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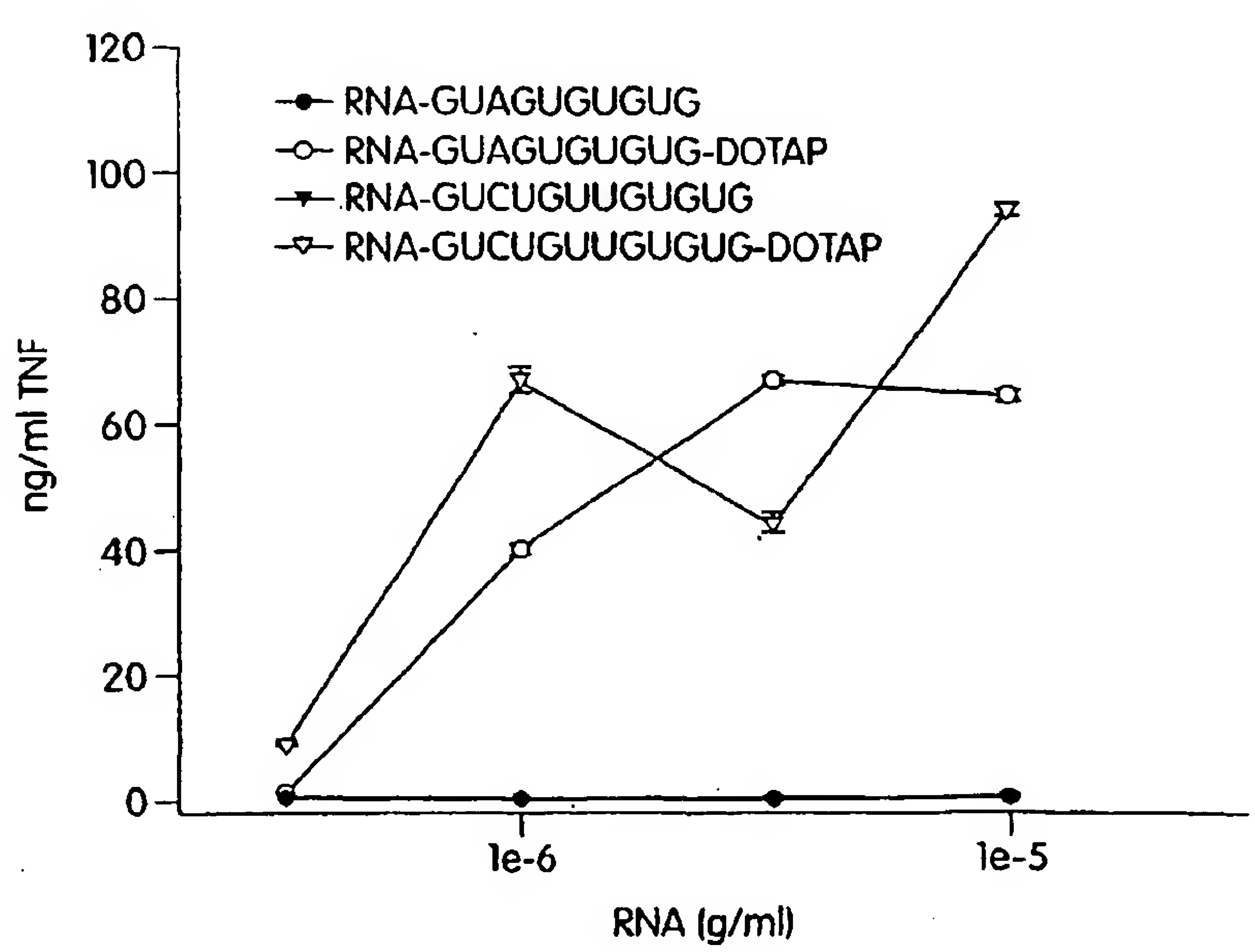
(54) Title: IMMUNOSTIMULATORY G,U-CONTAINING OLIGORIBONUCLEOTIDES



(57) Abstract: Compositions and methods relating to immunostimulatory RNA oligomers are provided. The immunostimulatory RNA molecules are believed to represent natural ligands of one or more Toll-like receptors, including Toll-like receptor 7 (TLR7) and Toll-like receptor 8 (TLR8). The compositions and methods are useful for stimulating immune activation. Methods useful for screening candidate immunostimulatory compounds are also provided.

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IMMUNOSTIMULATORY G,U-CONTAINING OLIGORIBONUCLEOTIDES

Field of the Invention

The present invention relates generally to the field of immunology and immune stimulation. More particularly, the present invention relates to immunostimulatory ribonucleic acids, homologs of said immunostimulatory ribonucleic acids, and methods of use of said immunostimulatory ribonucleic acids and homologs. Compositions and methods of the invention are believed to be useful for inducing signaling through Toll-like receptor 7 (TLR7) and Toll-like receptor 8 (TLR8).

Background of the Invention

The immune response is conceptually divided into innate immunity and adaptive immunity. Innate immunity is believed to involve recognition of pathogen-associated molecular patterns (PAMPs) shared in common by certain classes of molecules expressed by infectious microorganisms or foreign macromolecules. PAMPs are believed to be recognized by pattern recognition receptors (PRRs) on certain immune cells.

Toll-like receptors (TLRs) are a family of highly conserved polypeptides that play a critical role in innate immunity in mammals. Currently ten family members, designated TLR1 - TLR10, have been identified. The cytoplasmic domains of the various TLRs are characterized by a Toll-interleukin 1 (IL-1) receptor (TIR) domain. Medzhitov R et al. (1998) *Mol Cell* 2:253-8. Recognition of microbial invasion by TLRs triggers activation of a signaling cascade that is evolutionarily conserved in *Drosophila* and mammals. The TIR domain-containing adapter protein MyD88 has been reported to associate with TLRs and to recruit IL-1 receptor-associated kinase (IRAK) and tumor necrosis factor (TNF) receptor-associated factor 6 (TRAF6) to the TLRs. The MyD88-dependent signaling pathway is believed to lead to activation of NF-kB transcription factors and c-Jun NH_2 terminal kinase (Jnk) mitogen-activated protein kinases (MAPKs), critical steps in immune activation and production of inflammatory cytokines. For a review, see Aderem A et al. (2000) *Nature* 406:782-87.

While a number of specific TLR ligands have been reported, ligands for some TLRs remain to be identified. Ligands for TLR2 include peptidoglycan and lipopeptides. Yoshimura A et al. (1999) *J Immunol* 163:1-5; Yoshimura A et al. (1999) *J Immunol* 163:1-5;

Aliprantis AO et al. (1999) *Science* 285:736-9. Viral-derived double-stranded RNA (dsRNA) and poly I:C, a synthetic analog of dsRNA, have been reported to be ligands of TLR3. Alexopoulou L et al. (2001) *Nature* 413:732-8. Lipopolysaccharide (LPS) is a ligand for TLR4. Poltorak A et al. (1998) *Science* 282:2085-8; Hoshino K et al. (1999) *J Immunol* 162:3749-52. Bacterial flagellin is a ligand for TLR5. Hayashi F et al. (2001) *Nature* 410:1099-1103. Peptidoglycan has been reported to be a ligand not only for TLR2 but also for TLR6. Ozinsky A et al. (2000) *Proc Natl Acad Sci USA* 97:13766-71; Takeuchi O et al. (2001) *Int Immunol* 13:933-40. Bacterial DNA (CpG DNA) has been reported to be a TLR9 ligand. Hemmi H et al. (2000) *Nature* 408:740-5; Bauer S et al. (2001) *Proc Natl Acad Sci USA* 98, 9237-42. The TLR ligands listed above all include natural ligands, i.e., TLR ligands found in nature as molecules expressed by infectious microorganisms.

The natural ligands for TLR1, TLR7, TLR8 and TLR10 are not known, although recently certain low molecular weight synthetic compounds, the imidazoquinolones imiquimod (R-837) and resiquimod (R-848), were reported to be ligands of TLR7. Hemmi H et al. (2002) *Nat Immunol* 3:196-200.

Summary of the Invention

The present invention is based in part on the novel discovery by the inventors of certain immunostimulatory RNA and RNA-like (hereinafter, simply "RNA") molecules. The immunostimulatory RNA molecules of the invention are believed by the inventors to require a base sequence that includes at least one guanine (G) and at least one uracil (U), wherein optionally the at least one G can be a variant or homolog of G and/or the at least one U can independently be a variant or homolog of U. Surprisingly, the immunostimulatory RNA molecules of the invention can be either single-stranded or at least partially double-stranded. Also surprisingly, the immunostimulatory RNA molecules of the invention do not require a CpG motif in order to exert their immunostimulatory effect. Without meaning to be bound by any particular theory or mechanism, it is the belief of the inventors that the immunostimulatory RNA molecules of the invention signal through an MyD88-dependent pathway, probably through a TLR. Also without meaning to be bound by any particular theory or mechanism, it is the belief of the inventors that the immunostimulatory RNA molecules of the invention interact with and signal through TLR8, TLR7, or some other TLR yet to be identified.

The immunostimulatory RNA molecules of the invention are also believed by the inventors to be representative of a class of RNA molecules, found in nature, which can induce an immune response. Without meaning to be bound by any particular theory or mechanism, it is the belief of the inventors that the corresponding class of RNA molecules found in nature is believed to be present in ribosomal RNA (rRNA), transfer RNA (tRNA), messenger RNA (mRNA), and viral RNA (vRNA). It is to be noted in this regard that the immunostimulatory RNA molecules of the present invention can be as small as 5-40 nucleotides long. Such short RNA molecules fall outside the range of full length messenger RNAs described to be useful in transfecting dendritic cells in order to induce an immune response to cancer antigens. See, e.g., Boczkowski D et al. (1996) *J Exp Med* 184:465-72; Mitchell DA et al. (2000) *Curr Opin Mol Ther* 2:176-81.

It has also been discovered according to the present invention that the immunostimulatory RNA molecules of the invention can be advantageously combined with with certain agents which promote stabilization of the RNA, local clustering of the RNA molecules, and/or trafficking of the RNA molecules into the endosomal compartment of cells. In particular, it has been discovered according to the present invention that certain lipids and/or liposomes are useful in this regard. For example, certain cationic lipids, including in particular N-[1-(2, 3 dioleoyloxy)-propyl]-N,N,N-trimethylammonium methyl-sulfate (DOTAP), appear to be especially advantageous when combined with the immunostimulatory RNA molecules of the invention. As another example, covalent conjugation of a cholesteryl moiety to the RNA, for example to the 3′ end of the RNA, promotes the immunostimulatory effect of the RNA, even in the absence of cationic lipid.

The invention provides compositions of matter and methods related to the immunostimulatory RNA molecules of the invention. The compositions and methods are useful, inter alia, for activating immune cells in vivo, in vitro, and ex vivo; treating infection; treating cancer; preparing a pharmaceutical composition; identifying a target receptor for the immunostimulatory RNA; and screening for and characterizing additional immunostimulatory compounds. Furthermore, the compositions of matter and methods related to the immunostimulatory RNA molecules of the instant invention can advantageously be combined with other immunostimulatory compositions of matter and methods related to such other immunostimulatory compositions of matter.

In one aspect the invention provides an immunostimulatory composition. The immunostimulatory composition according to this aspect of the invention includes an isolated RNA oligomer 5-40 nucleotides long having a base sequence having at least one guanine (G) and at least one uracil (U), and optionally a cationic lipid. The RNA oligomer can be of natural or non-natural origin. An RNA oligomer of natural origin can in one embodiment be derived from prokaryotic RNA and in another embodiment can be derived from eukaryotic RNA. In addition, the RNA oligomer of natural origin can include a portion of a ribosomal RNA. An RNA oligomer of non-natural origin can include an RNA molecule synthesized outside of a cell, e.g., using chemical techniques known by those of skill in the art. In one embodiment an RNA oligomer can include a derivative of an RNA oligomer of natural origin.

In one embodiment the isolated RNA oligomer is a G,U-rich RNA as defined below.

In one embodiment the G,U-containing immunostimulatory RNA is an isolated RNA molecule at least 5 nucleotides long which includes a base sequence as provided by 5′-RURGY-3′, wherein R represents purine, U represents uracil, G represents guanine, and Y represents pyrimidine. In one embodiment the G,U-containing immunostimulatory RNA is an isolated RNA molecule at least 5 nucleotides long which includes a base sequence as provided by 5′-GUAGU-3′, wherein A represents adenine. In one embodiment the G,U-containing immunostimulatory RNA is an isolated RNA molecule which includes a base sequence as provided by 5′-GUAGUGU-3′.

In one embodiment the G,U-containing immunostimulatory RNA is an isolated RNA molecule at least 5 nucleotides long which includes a base sequence as provided by 5′-GUUGB-3′, wherein B represents U, G, or C.

In one embodiment the G,U-containing immunostimulatory RNA is an isolated RNA molecule at least 5 nucleotides long which includes a base sequence as provided by 5′-GUGUG-3′.

In other embodiments the isolated RNA molecule can contain multiples of any of the foregoing sequences, combinations of any of the foregoing sequences, or combinations of any of the foregoing sequences including multiples of any of the foregoing sequences. The multiples and combinations can be linked directly or they can be linked indirectly, i.e, through an intervening nucleoside or sequence. In one embodiment the intervening linking nucleoside is G; in one embodiment the intervening linking nucleoside is U.

In one embodiment the base sequence includes 5'-GUGUUUAC-3'. In one embodiment the base sequence is 5'-GUGUUUAC-3'.

In another embodiment the the base sequence includes 5'-GUAGGCAC-3'. In one embodiment the the base sequence is 5'-GUAGGCAC-3'.

In yet another embodiment the base sequence includes 5'-CUAGGCAC-3'. In one embodiment the base sequence is 5'-CUAGGCAC-3'.

In still another embodiment the base sequence includes 5'-CUCGGCAC-3'. In one embodiment the base sequence is 5'-CUCGGCAC-3'.

In one embodiment the oligomer is 5-12 nucleotides long. In one embodiment the oligomer is 8-12 nucleotides long.

Also according to this aspect of the invention, in one embodiment the base sequence is free of CpG dinucleotide. Thus in this embodiment the immunostimulatory RNA is not a CpG nucleic acid.

In certain embodiments according to this aspect of the invention, the base sequence of the RNA oligomer is at least partially self-complementary. In one embodiment the extent of self-complementarity is at least 50 percent. The extent of self-complementarity can extend to and include 100 percent. Thus for example the base sequence of the at least partially self-complementary RNA oligomer in various embodiments can be at least 50 percent, at least 60 percent, at least 70 percent, at least 80 percent, at least 90 percent, or 100 percent self-complementary. Complementary base pairs include guanine-cytosine (G-C), adenine-uracil (A-U), adenine-thymine (A-T), and guanine-uracil (G-U). G-U "wobble" basepairing, which is fairly common in ribosomal RNA and in RNA retroviruses, is somewhat weaker than traditional Watson-Crick basepairing between G-C, A-T, or A-U. A partially self-complementary sequence can include one or more portions of self-complementary sequence. In an embodiment which involves a partially self-complementary sequence, the RNA oligomer can include a self-complementary portion positioned at and encompassing each end of the oligomer.

In one embodiment according to this aspect of the invention, the oligomer is a plurality of oligomers, i.e., a plurality of RNA oligomers each 6-40 nucleotides long having a base sequence comprising at least one guanine (G) and at least one uracil (U). The plurality of oligomers can, but need not, include sequences which are at least partially complementary to one another. In one embodiment the plurality of oligomers includes an oligomer having a

first base sequence and an oligomer having a second base sequence, wherein the first base sequence and the second base sequence are at least 50 percent complementary. Thus for example the at least partially complementary base sequences in various embodiments can be at least 50 percent, at least 60 percent, at least 70 percent, at least 80 percent, at least 90 percent, or 100 percent complementary. As described above, complementary base pairs include guanine-cytosine (G-C), adenine-uracil (A-U), adenine-thymine (A-T), and guanine-uracil (G-U). Partially complementary sequences can include one or more portions of complementary sequence. In an embodiment which involves partially complementary sequences, the RNA oligomers can include a complementary portion positioned at and encompassing at least one end of the oligomers.

In one embodiment the oligomer is a plurality of oligomers which includes an oligomer having a base sequence including 5'-GUGUUUAC-3' and an oligomer having a base sequence including 5'-GUAGGCAC-3'. In one embodiment the oligomer is a plurality of oligomers which includes an oligomer having a base sequence 5'-GUGUUUAC-3' and an oligomer having a base sequence 5'-GUAGGCAC-3'.

Further according to this aspect of the invention, in various embodiments the oligomer includes a non-natural backbone linkage, a modified base, a modified sugar, or any combination of the foregoing. The non-natural backbone linkage can be a stabilized linkage, i.e., a linkage which is relatively resistant against RNAse or nuclease degradation, compared with phosphodiester linkage. In one embodiment the non-natural backbone linkage is a phosphorothioate linkage. The oligomer can include one non-natural backbone linkage or a plurality of non-natural backbone linkages, each selected independently of the rest. The modified base can be a modified G, U, A, or C, including the at least one G and the at least one U of the base sequence according to this aspect of the invention. In some embodiments the modified base can be selected from 7-deazaguanosine, 8-azaguanosine, 5-methyluracil, and pseudouracil. The oligomer can include one modified base or a plurality of modified bases, each selected independently of the rest. The modified sugar can be a methylated sugar, arabinose. The oligomer can include one modified sugar or a plurality of modified sugars, each selected independently of the rest.

In one embodiment the cationic lipid is N-[1-(2,3-dioleoyloxy)propyl]-N,N,N-trimethylammonium methyl-sulfate (DOTAP). DOTAP is believed to transport RNA oligomer into cells and specifically traffic to the endosomal compartment, where it can

release the RNA oligomer in a pH-dependent fashion. Once in the endosomal compartment, the RNA can interact with certain intracellular Toll-like receptor molecules (TLRs), triggering TLR-mediated signal transduction pathways involved in generating an immune response. Other agents with similar properties including trafficking to the endosomal compartment can be used in place of or in addition to DOTAP.

In one embodiment the immunostimulatory composition further includes an antigen. In one embodiment the antigen is an allergen. In one embodiment the antigen is a cancer antigen. In one embodiment the antigen is a microbial antigen.

Also according to this aspect of the invention, in another embodiment the invention is a pharmaceutical composition. The pharmaceutical composition includes an immunostimulatory composition of the invention and a pharmaceutically acceptable carrier. Methods for preparing the pharmaceutical composition are also provided. Such methods entail placing an immunostimulatory composition of the invention in contact with a pharmaceutically acceptable carrier. The pharmaceutical composition can be formulated in a unit dosage for convenience.

In another aspect the invention provides a method of activating an immune cell. The method involves contacting an immune cell with an immunostimulatory composition of the invention, described above, in an effective amount to induce activation of the immune cell. In one embodiment the activation of the immune cell involves secretion of a cytokine by the immune cell. The cytokine in one embodiment is selected from the group consisting of interleukin 6 (IL-6), interleukin 12 (IL-12), an interferon (IFN), and tumor necrosis factor (TNF). In one embodiment the activation of the immune cell includes secretion of a chemokine. In one embodiment the secreted chemokine is interferon-gamma-induced protein 10 (IP-10). In one embodiment the activation of the immune cell includes expression of a costimulatory/accessory molecule by the immune cell. In one embodiment the costimulatory/accessory molecule is selected from the group consisting of intercellular adhesion molecules (ICAMs, e.g., CD54), leukocyte function-associated antigens (LFAs, e.g., CD58), B7s (CD80, CD86), and CD40.

Also according to this aspect of the invention, in one embodiment the activation of the immune cell involves activation of a MyD88-dependent signal transduction pathway. MyD88 is believed to be an adapter molecule that interacts with the Toll/interleukin-1 receptor (TIR) domain of various Toll-like receptor (TLR) molecules and participates in

signal transduction pathways that ultimately result in activation of nuclear factor kappa B (NF-κB). Thus in one embodiment the MyD88-dependent signal transduction pathway is associated with a TLR. More particularly, in one embodiment the TLR is TLR8. In another embodiment the TLR is TLR7.

Also according to this aspect of the invention in one embodiment the immune cell is a human immune cell. The immune cell in one embodiment is a myeloid dendritic cell.

In one embodiment of this aspect of the invention the contacting occurs in vitro. In another embodiment the contacting occurs in vivo.

The invention in another aspect provides a method of inducing an immune response in a subject. The method according to this aspect of the invention involves administering to a subject an immunostimulatory composition of the invention in an effective amount to induce an immune response in the subject. It is to be noted that the method according to this aspect of the invention does not involve administration of an antigen to the subject. In one embodiment the subject is a human. In one embodiment the subject has or is at risk of having a cancer. In one embodiment the subject has or is at risk of having an infection with an agent selected from the group consisting of viruses, bacteria, fungi, and parasites. In a particular embodiment the subject has or is at risk of having a viral infection. It is also to be noted that the method according to this aspect of the invention can be used to treat a subject with a suppressed capacity to mount an effective or desirable immune response. For example the subject can have a suppressed immune system due to an infection, a cancer, an acute or chronic disease such as kidney or liver insufficency, surgery, and an exposure to an immunosuppressive agent such as chemotherapy, radiation, certain drugs, or the like. In one embodiment the subject has or is at risk of having an allergy or asthma. Such a subject can be exposed to or at risk of exposure to an allergen that is associated with an allergic response or asthma in the subject.

In yet another aspect the invention provides a method of inducing an immune response in a subject. The method according to this aspect of the invention involves administering an antigen to a subject, and administering to the subject an immunostimulatory composition of the invention in an effective amount to induce an immune response to the antigen. It is to be noted that the antigen can be administered before, after, or concurrently with the immunostimulatory composition of the invention. In addition, both the antigen and the immunostimulatory compound can be administered to the subject more than once.

In one embodiment according to this aspect of the invention the antigen is an allergen. In one embodiment according to this aspect of the invention the antigen is a cancer antigen. The cancer antigen in one embodiment can be a cancer antigen isolated from the subject. In another embodiment the antigen is a microbial antigen. The microbial antigen can be an antigen of a virus, a bacterium, a fungus, or a parasite.

The invention further provides, in yet another aspect, a method of inducing an immune response in a subject. The method according to this aspect of the invention involves isolating dendritic cells of a subject, contacting the dendritic cells ex vivo with an immunostimulatory composition of the invention, contacting the dendritic cells ex vivo with an antigen, and administering the contacted dendritic cells to the subject.

In one embodiment according to this aspect of the invention the antigen is an allergen. In one embodiment according to this aspect of the invention the antigen is a cancer antigen. The cancer antigen in one embodiment can be a cancer antigen isolated from the subject. In another embodiment the antigen is a microbial antigen. The microbial antigen can be an antigen of a virus, a bacterium, a fungus, or a parasite.

An immune response arising from stimulation of one TLR can be modified, enhanced or amplified by stimulation of another TLR, and the combined immunostimulatory effect may be synergistic. For example, TLR9 is reported to respond to bacterial DNA and, more generally, CpG DNA. An immune response arising from TLR9 contacting its natural ligand (or any TLR9 ligand) may be modified, enhanced or amplified by also selectively contacting TLR7 with a TLR7 ligand, or by also selectively contacting TLR8 with a TLR8 ligand, or both. Likewise, an immune response arising from TLR7 contacting a TLR7 ligand may be modified, enhanced or amplified by also selectively contacting TLR8 with a TLR8 ligand, or by also selectively contacting TLR9 with CpG DNA (or any suitable TLR9 ligand), or both. As yet another example, an immune response arising from TLR8 contacting a TLR8 ligand may be modified, enhanced or amplified by also selectively contacting TLR7 with a TLR7 ligand, or by also selectively contacting TLR9 with CpG DNA (or any suitable TLR9 ligand), or both.

The present invention is based in part on the novel discovery by the inventors of what are believed to be natural ligands for TLR7 and TLR8. While naturally occurring ligands derived from microbes have been described for certain TLRs, natural ligands for TLR7 and TLR8 have not previously been described. Certain synthetic small molecules,

imidazoquinoline compounds, have been described as ligands for TLR7, but such compounds are to be distinguished from the natural ligands of the present invention. Hemmi H et al. (2002) *Nat Immunol* 3:196-200.

Isolated natural ligands of TLR7 and TLR8 are useful as compositions that can induce, enhance, and complement an immune response. The natural ligands of TLR7 and TLR8 are useful for preparation of novel compositions that can induce, enhance, and complement an immune response. In addition, the natural ligands of TLR7 and TLR8 are useful for selectively inducing TLR7- and TLR8-mediated signaling and for selectively inducing TLR7- and TLR8-mediated immune responses. Furthermore, the natural ligands of TLR7 and TLR8 are useful in designing and performing screening assays for identification and selection of immunostimulatory compounds.

The present invention is also based in part on the novel discovery according to the invention that human neutrophils strongly express TLR8. This observation is important because neutrophils are very often the first cells to engage infectious pathogens and thus to initiate responses. It is believed that activated neutrophils secrete chemokines and cytokines, which in turn are instrumental in recruiting dendritic cells. TLR9-expressing dendritic cells drawn to the site of the activated neutrophils there become activated, thereby amplifying the immune response.

The present invention is also based in part on the appreciation of the differential expression of various TLRs, including TLR7, TLR8, and TLR9, on various cells of the immune system. This segregation may be of particular significance in humans with respect to TLR7, TLR8, and TLR9. The immune response arising from stimulation of any one of these TLRs may be enhanced or amplified by stimulation of another TLR, and the combined immunostimulatory effect may be synergistic. For example, TLR9 is reported to respond to bacterial DNA and, more generally, CpG DNA. An immune response arising from TLR9 contacting its natural ligand (or any TLR9 ligand) may be enhanced or amplified by also selectively contacting TLR7 with its natural ligand (or any suitable TLR7 ligand), or by also selectively contacting TLR8 with its natural ligand (or any suitable TLR8 ligand), or both. Likewise, an immune response arising from TLR7 contacting its natural ligand (or any TLR7 ligand) may be enhanced or amplified by also selectively contacting TLR8 with its natural ligand (or any suitable TLR8 ligand), or by also selectively contacting TLR9 with CpG DNA (or any suitable TLR9 ligand), or both. As yet another example, an immune response arising

from TLR8 contacting its natural ligand (or any TLR8 ligand) may be enhanced or amplified by also selectively contacting TLR7 with its natural ligand (or any suitable TLR7 ligand), or by also selectively contacting TLR9 with CpG DNA (or any suitable TLR9 ligand), or both.

In a further aspect the invention provides a composition including an effective amount of a ligand for TLR8 to induce TLR8 signaling and an effective amount of a ligand for a second TLR selected from the group consisting of: TLR1, TLR2, TLR3, TLR4, TLR5, TLR6, TLR7, TLR9 and TLR10 to induce signaling by the second TLR. In one embodiment the second TLR is TLR3. In one embodiment the second TLR is TLR7. In one embodiment the second TLR is TLR9. In one embodiment the ligand for TLR8 and the ligand for the second TLR are linked. In yet another embodiment the composition further includes a pharmaceutically acceptable carrier.

In another aspect the invention provides a composition including an effective amount of a ligand for TLR7 to induce TLR7 signaling and an effective amount of a ligand for a second TLR selected from the group consisting of: TLR1, TLR2, TLR3, TLR4, TLR5, TLR6, TLR8, TLR9, and TLR10 to induce signaling by the second TLR. In one embodiment the second TLR is TLR3. In one embodiment the second TLR is TLR8. In one embodiment the second TLR is TLR9. In one embodiment the ligand for TLR7 and the ligand for the second TLR are linked. In yet another embodiment the composition further includes a pharmaceutically acceptable carrier.

In a further aspect the invention provides a composition including a DNA:RNA conjugate, wherein DNA of the conjugate includes an immunostimulatory motif effective for stimulating TLR9 signaling and wherein RNA of the conjugate includes RNA effective for stimulating signaling by TLR3, TLR7, TLR8, or any combination thereof. In one embodiment the immunostimulatory motif effective for stimulating TLR9 signaling is a CpG motif. In another embodiment the immunostimulatory motif effective for stimulating TLR9 signaling is poly-dT. In yet another embodiment the immunostimulatory motif effective for stimulating TLR9 signaling is poly-dG. In one embodiment the conjugate includes a chimeric DNA:RNA backbone. In one embodiment the chimeric backbone includes a cleavage site between the DNA and the RNA. In one embodiment the conjugate includes a double-stranded DNA:RNA heteroduplex. In yet another embodiment the composition further includes a pharmaceutically acceptable carrier.

In another aspect the invention provides a method for stimulating TLR8 signaling. The method involves contacting TLR8 with an isolated RNA in an effective amount to stimulate TLR8 signaling. In one embodiment the RNA is double-stranded RNA. In one embodiment the RNA is ribosomal RNA. In one embodiment the RNA is transfer RNA. In one embodiment the RNA is messenger RNA. In one embodiment the RNA is viral RNA. In one embodiment the RNA is G,U-rich RNA. In one embodiment the RNA consists essentially of G and U.

In yet another aspect the invention provides a method for stimulating TLR8 signaling. The method according to this aspect involves contacting TLR8 with a mixture of nucleosides consisting essentially of G and U in a ratio between 1G:50U and 10G:1U, in an amount effective to stimulate TLR8 signaling. In one embodiment the nucleosides are ribonucleosides. In one embodiment the nucleosides comprise a mixture of ribonucleosides and deoxyribonucleosides. In one embodiment the G is a guanosine derivative selected from the group consisting of: 8-bromoguanosine, 8-oxoguanosine, 8-mercaptoguanosine, 7-allyl-8-oxoguanosine, guanosine ribonucleoside vanadyl complex, inosine, and nebularine.

A further aspect of the invention provides a method for stimulating TLR8 signaling. The method according to this aspect involves contacting TLR8 with a mixture of ribonucleoside vanadyl complexes. In one embodiment the mixture comprises guanosine ribonucleoside vanadyl complexes.

In another aspect the invention provides a method for stimulating TLR8 signaling. The method according to this aspect involves contacting TLR8 with an isolated G,U-rich oligonucleotide comprising a sequence selected from the group consisting of: UUGUGG, UGGUUG, GUGUGU, and GGGUUU, in an amount effective to stimulate TLR8 signaling. In one embodiment the oligonucleotide is an oligoribonucleotide. In one embodiment the oligonucleotide is 7-50 bases long. In one embodiment the oligonucleotide is 12-24 bases long. In one embodiment the oligonucleotide has a sequence 5'-GUUGUGGUUGUGGUUGUG-3' (SEQ ID NO:1).

The invention provides in another aspect a method for stimulating TLR8 signaling. The method according to this aspect involves contacting TLR8 with an at least partially double-stranded nucleic acid molecule comprising at least one G-U base pair, in an amount effective to stimulate TLR8 signaling.

In yet another aspect the invention provides a method for supplementing a TLR8-mediated immune response. The method involves contacting TLR8 with an effective amount of a TLR8 ligand to induce a TLR8-mediated immune response, and contacting a TLR other than TLR8 with an effective amount of a ligand for the TLR other than TLR8 to induce an immune response mediated by the TLR other than TLR8.

In a further aspect the invention provides a method for supplementing a TLR8-mediated immune response in a subject. The method according to this aspect involves administering to a subject in need of an immune response an effective amount of a TLR8 ligand to induce a TLR8-mediated immune response, and administering to the subject an effective amount of a ligand for a TLR other than TLR8 to induce an immune response mediated by the TLR other than TLR8. In one embodiment the TLR other than TLR8 is TLR9. In one embodiment the ligand for TLR9 is a CpG nucleic acid. In one embodiment the CpG nucleic acid has a stabilized backbone. In one embodiment the ligand for TLR8 and the ligand for TLR9 are a conjugate. In one embodiment the conjugate comprises a double-stranded DNA:RNA heteroduplex. In one embodiment the conjugate comprises a chimeric DNA:RNA backbone. In one embodiment the chimeric backbone comprises a cleavage site between the DNA and the RNA.

The invention in a further aspect provides a method for stimulating TLR7 signaling. The method according to this aspect involves contacting TLR7 with an isolated guanosine ribonucleoside in an effective amount to stimulate TLR7 signaling. In one embodiment the guanosine ribonucleoside is a guanosine ribonucleoside derivative selected from the group consisting of: 8-bromoguanosine, 8-oxoguanosine, 8-mercaptoguanosine, 7-allyl-8-oxoguanosine, guanosine ribonucleoside vanadyl complex, inosine, and nebularine. In one embodiment the guanosine ribonucleoside derivative is 8-oxoguanosine. In one embodiment the guanosine nucleoside is a ribonucleoside. In one embodiment the guanosine nucleoside comprises a mixture of ribonucleosides and deoxyribonucleosides.

In another aspect the invention further provides a method for stimulating TLR7 signaling. The method according to this aspect involves contacting TLR7 with an isolated nucleic acid comprising a terminal oxidized or halogenized guanosine in an effective amount to stimulate TLR7 signaling. In one embodiment the oxidized or halogenized guanosine is 8-oxoguanosine.

In another aspect the invention provides a method for stimulating TLR7 signaling. The method according to this aspect involves contacting TLR7 with an isolated RNA in an effective amount to stimulate TLR7 signaling. In one embodiment the RNA is double-stranded RNA. In one embodiment the RNA is ribosomal RNA. In one embodiment the RNA is transfer RNA. In one embodiment the RNA is messenger RNA. In one embodiment the RNA is viral RNA. In one embodiment the RNA is G-rich RNA. In one embodiment the RNA is part of a DNA:RNA heteroduplex. In one embodiment the RNA consists essentially of guanosine ribonucleoside.

The invention in yet another aspect provides a method for stimulating TLR7 signaling. The method according to this aspect involves contacting TLR7 with a mixture of nucleosides consisting essentially of G and U in a ratio between 1G:50U and 10G:1U, in an amount effective to stimulate TLR7 signaling.

Provided in yet another aspect of the invention is a method for stimulating TLR7 signaling. The method according to this aspect involves contacting TLR7 with a mixture of ribonucleoside vanadyl complexes. In one embodiment the mixture comprises guanosine ribonucleoside vanadyl complexes.

In a further aspect the invention provides a method for supplementing a TLR7-mediated immune response. The method according to this aspect involves contacting TLR7 with an effective amount of a TLR7 ligand to induce a TLR7-mediated immune response, and contacting a TLR other than TLR7 with an effective amount of a ligand for the TLR other than TLR7 to induce an immune response mediated by the TLR other than TLR7.

In yet another aspect the invention provides a method for supplementing a TLR7-mediated immune response in a subject. The method involves administering to a subject in need of an immune response an effective amount of a TLR7 ligand to induce a TLR7-mediated immune response, and administering to the subject an effective amount of a ligand for a TLR other than TLR7 to induce an immune response mediated by the TLR other than TLR7. In one embodiment the TLR other than TLR7 is TLR9. In one embodiment the ligand for TLR9 is a CpG nucleic acid. In one embodiment the CpG nucleic acid has a stabilized backbone. In one embodiment the ligand for TLR7 and the ligand for TLR9 are a conjugate. In one embodiment the conjugate comprises a double-stranded DNA:RNA heteroduplex. In one embodiment the conjugate comprises a chimeric DNA:RNA backbone.

In one embodiment the chimeric backbone comprises a cleavage site between the DNA and the RNA.

The invention in another aspect provides a method for screening candidate immunostimulatory compounds. The method according to this aspect involves measuring a TLR8-mediated reference signal in response to an RNA reference, measuring a TLR8-mediated test signal in response to a candidate immunostimulatory compound, and comparing the TLR8-mediated test signal to the TLR8-mediated reference signal.

In yet another aspect the invention provides a method for screening candidate immunostimulatory compounds, comprising measuring a TLR8-mediated reference signal in response to an imidazoquinoline reference, measuring a TLR8-mediated test signal in response to a candidate immunostimulatory compound, and comparing the TLR8-mediated test signal to the TLR8-mediated reference signal.

Also provided according to yet another aspect of the invention is a method for screening candidate immunostimulatory compounds. The method involves measuring a TLR7-mediated reference signal in response to an imidazoquinoline reference, measuring a TLR7-mediated test signal in response to a candidate immunostimulatory compound, and comparing the TLR7-mediated test signal to the TLR7-mediated reference signal.

In some embodiments the imidazoquinoline is resiquimod (R-848).

In some embodiments the imidazoquinoline is imiquimod (R-837).

In a further aspect the invention also provides a method for screening candidate immunostimulatory compounds. The method according to this aspect involves measuring a TLR7-mediated reference signal in response to a 7-allyl-8-oxoguanosine reference, measuring a TLR7-mediated test signal in response to a candidate immunostimulatory compound, and comparing the TLR7-mediated test signal to the TLR7-mediated reference signal.

Each of the limitations of the invention can encompass various embodiments of the invention. It is, therefore, anticipated that each of the limitations of the invention involving any one element or combinations of elements can be included in each aspect of the invention.

Brief Description of the Figures

FIG. 1 is a bar graph depicting IL-12 p40 secretion by human peripheral blood mononuclear cells (PBMCs) in response to certain stimuli including selected G,U-containing

RNA oligonucleotides with or without DOTAP ("with Liposomes" and "without Liposomes", respectively), as measured by specific enzyme-linked immunosorbent assay (ELISA). The lower case letter "s" appearing in the base sequences signifies phosphorothioate linkage.

FIG. 2 is a bar graph depicting TNF-α secretion by human PBMCs in response to certain stimuli including selected G,U-containing RNA oligonucleotides with or without DOTAP ("with Liposomes" and "without Liposomes", respectively), as measured by specific ELISA.

FIG. 3 is a bar graph depicting dose-dependence of IL-12 p40 secretion by human PBMCs in response to various concentrations of selected G,U-containing RNA oligonucleotides (with DOTAP), as measured by specific ELISA.

FIG. 4 is a bar graph depicting sequence dependence of TNF-α secretion by human PBMCs in response to various selected RNA oligonucleotides related to the RNA oligonucleotide GUAGGCAC (with DOTAP), as measured by specific ELISA.

FIG. 5 is a bar graph depicting the effect of DOTAP on IL-12 p40 secretion by human PBMCs in response to various stimuli, as measured by specific ELISA.

FIG. 6 is a quartet of bar graphs depicting IL-12 p40 secretion by various types of murine macrophage cells in response to a variety of test and control immunostimulatory compounds, as measured by specific ELISA. Panel A, wild type macrophages in the presence of IFN-γ; Panel B, MyD88-deficient macrophages in the presence of IFN-γ; Panel C, J774 macrophage cell line; Panel D, RAW 264.7 macrophage cell line.

FIG. 7 is a pair of graphs depicting the secretion of (A) TNF-α and (B) IL-12 p40 by human PBMC upon incubation with HIV-1-derived RNA sequences, with and without DOTAP. Circles, 5'-GUAGUGUGUG-3' (SEQ ID NO:2); Triangles, 5'-GUCUGUUGUGUG-3' (SEQ ID NO:3). Open symbols, without DOTAP; closed symbols, with DOTAP.

FIG. 8 is a graph depicting apparent relatedness among TLRs.

FIG. 9 depicts nucleic acid binding domains in TLR7, TLR8, and TLR9.

FIG. 10 is a bar graph depicting responsiveness of human PBMC to stringent response factor (SRF).

FIG. 11 is a bar graph depicting responsiveness of human PBMC to the ribonucleoside vanadyl complexes (RVCs). X denotes resiquimod.

FIG. 12 is a series of three bar graphs depicting responsiveness of human TLR7 and human TLR8 to individual ribonucleosides. X denotes resiquimod.

FIG. 13 is a series of three bar graphs depicting responsiveness of TLR7 and TLR8 to mixtures of two ribonucleosides.

FIG. 14 is a bar graph depicting response of human PBMC to a mixture of the ribonucleosides G and U.

FIG. 15 is a bar graph depicting response of human PBMC to G,U-rich RNA, but not DNA, oligonucleotides.

FIG. 16 is a bar graph depicting response of human PBMC to oxidized RNA.

FIG. 17 is a series of three bar graphs depicting human TLR7 and TLR8 responses to oxidized guanosine ribonucleoside. X denotes resiquimod.

FIG. 18 is a pair of bar graphs depicting human TLR7 responses to modified guanosine ribonucleosides.

FIG. 19 is a series of aligned gel images depicting differential expression of TLR1-TLR9 on human CD123+ dendritic cells (CD123+ DC), CD11c+ DC, and neutrophils.

FIG. 20 is a series of three graphs depicting the ability of short, single-stranded G,U-containing RNA oligomers to induce NF-κB in HEK-293 cells stably transfected with expression plasmid for human TLR7 or human TLR8.

Detailed Description of the Invention

The invention relates in part to the discovery by the inventors of a number of RNA and RNA-related molecules that are effective as immunostimulatory compounds. Identification of the immunostimulatory compounds arose through a systematic effort aimed at identifying naturally occurring ligands for TLR7 and TLR8. As a result of this effort, it has now been discovered that RNA and RNA-like molecules containing guanine (G) and uracil (U), including specific sequences containing G and U, are immunostimulatory and appear to act through an MyD88-dependent pathway, implicating TLR involvement. Significantly, some of the RNA sequences occur in highly conserved structural features of 5′ untranslated regions of viral RNA that are important to viral replication. The identified immunostimulatory RNA sequences also correspond to or very nearly correspond to other RNAs, including tRNAs derived from bacteria and yeast, as well as rRNA derived from bacteria and possibly some eukaryotes. Importantly, the immunostimulatory RNA of the

invention includes single-stranded RNA, in addition to partially or wholly double-stranded RNA, and its effect can be abrogated by RNase treatment. Where the RNA is at least partially double-stranded, it can in one embodiment include a stem-loop structure. As described in greater detail below, it has been discovered according to the invention that single-stranded G,U-rich RNAs as short as 5 nucleotides long can stimulate immune cells to produce large amounts of a number of cytokines and chemokines, includingTNF-α, IL-6, IL-12, type 1 interferon (e.g., IFN-α), and IP-10.

It has now been surprisingly discovered by the inventors that certain G,U-containing RNA molecules and their analogs, but not their DNA counterparts, are immunostimulatory. Significantly, the G,U-containing oligoribonucleotides of the invention can be substantially smaller than the messenger RNAs previously described to be useful in preparing dendritic cell vaccines. See, e.g., Boczkowski D et al. (1996) *J Exp Med* 184:465-72; Mitchell DA et al. (2000) *Curr Opin Mol Ther* 2:176-81. Although the G,U-containing RNA molecules of the invention can be surrogates for ribosomal RNA and/or viral RNA as found in nature, they can be as small as 5-40 nucleotides long. As described further herein, the G,U-containing oligoribonucleotides of the invention include at least one G and at least one U. Surprisingly, elimination of either G or U from the G,U-containing oligoribonucleotides of the invention essentially abrogates their immunostimulatory effect. The at least one G and at least U can be adjacent to one another, or they can be separated by intervening nucleosides or sequence. Also significantly, the immunostimulatory G,U-containing RNA molecules of the invention do not require a CpG dinucleotide.

In one aspect the invention provides an immunostimulatory composition. The immunostimulatory composition according to this aspect of the invention includes an isolated RNA oligomer 5-40 nucleotides long having a base sequence having at least one guanine (G) and at least one uracil (U). As will be described in greater detail further below, the immunostimulatory RNA oligomer 5-40 nucleotides long having a base sequence having at least one guanine (G) and at least one uracil (U) is advantageously formulated such that the RNA oligomer is stabilized against degradation, concentrated in or on a particle such as a liposome, and/or targeted for delivery to the endosomal compartment of cells. In one formulation, described in the examples below, the RNA oligomer is advantageously combined with the cationic lipid DOTAP, which is believed to assist in trafficking the G,U-containing oligoribonucleotides into the endosomal compartment. Thus, in one aspect the

invention is an immunostimulatory composition which includes an RNA oligomer 5-40 nucleotides long having a base sequence having at least one G and at least one U and optionally a cationic lipid.

The RNA oligomer of the invention can be of natural or non-natural origin. RNA as it occurs in nature is a type of nucleic acid that generally refers to a linear polymer of certain ribonucleoside units, each ribonucleoside unit made up of a purine or pyrimidine base and a ribose sugar, linked by internucleoside phosphodiester bonds. In this regard "linear" is meant to describe the primary structure of RNA. RNA in general can be single-stranded or double-stranded, including partially double-stranded.

As used herein, "nucleoside" refers to a single sugar moiety (e.g., ribose or deoxyribose) linked to an exchangeable organic base, which is either a substituted pyrimidine (e.g., cytosine (C), thymidine (T) or uracil (U)) or a substituted purine (e.g., adenine (A) or guanine (G)). As described herein, the nucleoside may be a naturally occuring nucleoside, a modified nucleoside, or a synthetic (artificial) nucleoside.

The terms "nucleic acid" and "oligonucleotide" are used interchangeably to mean multiple nucleotides (i.e., molecules comprising a sugar (e.g., ribose or deoxyribose) linked to a phosphate group and to an exchangeable organic base, which is either a substituted pyrimidine (e.g., cytosine (C), thymidine (T) or uracil (U)) or a substituted purine (e.g., adenine (A) or guanine (G)). As used herein, the terms refer to oligoribonucleotides as well as oligodeoxyribonucleotides. The terms shall also include polynucleosides (i.e., a polynucleotide minus the phosphate) and any other organic base-containing polymer. Nucleic acid molecules can be obtained from existing nucleic acid sources (e.g., genomic or cDNA), but are preferably synthetic (e.g., produced by nucleic acid synthesis).

The terms nucleic acid and oligonucleotide also encompass nucleic acids or oligonucleotides with substitutions or modifications, such as in the bases and/or sugars. For example, they include nucleic acids having backbone sugars which are covalently attached to low molecular weight organic groups other than a hydroxyl group at the 3' position and other than a phosphate group at the 5' position. Thus modified nucleic acids may include a 2'-O-alkylated ribose group. In addition, modified nucleic acids may include sugars such as arabinose instead of ribose. Thus the nucleic acids may be heterogeneous in backbone composition thereby containing any possible combination of polymer units linked together such as peptide nucleic acids (which have amino acid backbone with nucleic acid bases). In

some embodiments, the nucleic acids are homogeneous in backbone composition. Nucleic acids also include substituted purines and pyrimidines such as C-5 propyne modified bases. Wagner RW et al. (1996) *Nat Biotechnol* 14:840-4. Purines and pyrimidines include but are not limited to adenine, cytosine, guanine, thymidine, 5-methylcytosine, 2-aminopurine, 2-amino-6-chloropurine, 2,6-diaminopurine, hypoxanthine, and other naturally and non-naturally occurring nucleobases, substituted and unsubstituted aromatic moieties. Other such modifications are well known to those of skill in the art.

A natural nucleoside base can be replaced by a modified nucleoside base, wherein the modified nucleoside base is for example selected from hypoxanthine; dihydrouracil; pseudouracil; 2-thiouracil; 4-thiouracil; 5-aminouracil; 5-(C_1-C_6)-alkyluracil; 5-(C_2-C_6)-alkenyluracil; 5-(C_2-C_6)-alkynyluracil; 5-(hydroxymethyl)uracil; 5-chlorouracil; 5-fluorouracil; 5-bromouracil; 5-hydroxycytosine; 5-(C_1-C_6)-alkylcytosine; 5-(C_2-C_6)-alkenylcytosine; 5-(C_2-C_6)-alkynylcytosine; 5-chlorocytosine; 5-fluorocytosine; 5-bromocytosine; N^2-dimethylguanine; 2,4-diamino-purine; 8-azapurine (including, in particular, 8-azaguanine); a substituted 7-deazapurine (including, in particular, 7-deazaguanine), including 7-deaza-7-substituted and/or 7-deaza-8-substituted purine; or other modifications of a natural nucleoside bases. This list is meant to be exemplary and is not to be interpreted to be limiting.

In particular, the at least one guanine base of the immunostimulatory G,U-containing oligoribonucleotide can be a substituted or modified guanine such as 7-deazaguanine; 8-azaguanine; 7-deaza-7-substituted guanine (such as 7-deaza-7-(C2-C6)alkynylguanine); 7-deaza-8-substituted guanine; hypoxanthine; 2,6-diaminopurine; 2-aminopurine; purine; 8-substituted guanine such as 8-hydroxyguanine; and 6-thioguanine. This list is meant to be exemplary and is not to be interpreted to be limiting.

Also in particular, the at least one uracil base of the G,U-containing oligoribonucleotide can be a substituted or modified uracil such as pseudouracil and 5-methyluracil.

For use in the instant invention, the nucleic acids of the invention can be synthesized *de novo* using any of a number of procedures well known in the art. For example, the β-cyanoethyl phosphoramidite method (Beaucage SL et al. (1981) *Tetrahedron Lett* 22:1859); nucleoside H-phosphonate method (Garegg et al. (1986) *Tetrahedron Lett* 27:4051-4; Froehler et al. (1986) *Nucl Acid Res* 14:5399-407; Garegg et al. (1986)

Tetrahedron Lett 27:4055-8; Gaffney et al. (1988) *Tetrahedron Lett* 29:2619-22). These chemistries can be performed by a variety of automated nucleic acid synthesizers available in the market. These nucleic acids are referred to as synthetic nucleic acids. Alternatively, T-rich and/or TG dinucleotides can be produced on a large scale in plasmids, (see Sambrook T et al., "Molecular Cloning: A Laboratory Manual", Cold Spring Harbor laboratory Press, New York, 1989) and separated into smaller pieces or administered whole. Nucleic acids can be prepared from existing nucleic acid sequences (e.g., genomic or cDNA) using known techniques, such as those employing restriction enzymes, exonucleases or endonucleases. Nucleic acids prepared in this manner are referred to as isolated nucleic acid. An isolated nucleic acid generally refers to a nucleic acid which is separated from components which it is normally associated with in nature. As an example, an isolated nucleic acid may be one which is separated from a cell, from a nucleus, from mitochondria or from chromatin. The term "nucleic acid" encompasses both synthetic and isolated nucleic acid.

For use in vivo, the nucleic acids may optionally be relatively resistant to degradation (e.g., are stabilized). In some embodiments only specific portions of the nucleic acids may optionally be stabilized. A "stabilized nucleic acid molecule" shall mean a nucleic acid molecule that is relatively resistant to *in vivo* degradation (e.g., via an exo- or endo-nuclease). Stabilization can be a function of length or secondary structure. Nucleic acids that are tens to hundreds of kbs long are relatively resistant to in vivo degradation. For shorter nucleic acids, secondary structure can stabilize and increase their effect. For example, if the 3' end of an nucleic acid has self-complementarity to an upstream region, so that it can fold back and form a sort of stem loop structure, then the nucleic acid becomes stabilized and therefore exhibits more activity.

In certain embodiments according to this aspect of the invention, the base sequence of the RNA oligomer is at least partially self-complementary. A self-complementary sequence as used herein refers to a base sequence which, upon suitable alignment, may form intramolecular or, more typically, intermolecular basepairing between G-C, A-U, and/or G-U wobble pairs. In one embodiment the extent of self-complementarity is at least 50 percent. For example an 8-mer that is at least 50 percent self-complementary may have a sequence capable of forming 4, 5, 6, 7, or 8 G-C, A-U, and/or G-U wobble basepairs. Such basepairs may but need not necessarily involve bases located at either end of the self-complementary RNA oligomer. Where nucleic acid stabilization may be important to the RNA oligomers, it

may be advantageous to "clamp" together one or both ends of a double-stranded nucleic acid, either by basepairing or by any other suitable means. The degree of self-complementarity may depend on the alignment between oligomers, and such alignment may or may not include single- or multiple-nucleoside overhangs. In other embodiments, the degree of self-complementarity is at least 60 percent, at least 70 percent, at least 80 percent, at least 90 percent, or even 100 percent. The foregoing notwithstanding, it should be noted that double-strandedness is not a requirement of the RNA oligomers of the invention.

Similar considerations apply to intermolecular basepairing between RNA oligonucleotides of different base sequence. Thus where a plurality of RNA oligomers are used together, the plurality of oligomers may, but need not, include sequences which are at least partially complementary to one another. In one embodiment the plurality of oligomers includes an oligomer having a first base sequence and an oligomer having a second base sequence, wherein the first base sequence and the second base sequence are at least 50 percent complementary. For example, as between two 8-mers that are at least 50 percent complementary, they may form 4, 5, 6, 7, or 8 G-C, A-U, and/or G-U wobble basepairs. Such basepairs may but need not necessarily involve bases located at either end of the complementary RNA oligomers. The degree of complementarity may depend on the alignment between oligomers, and such alignment may or may not include single- or multiple-nucleoside overhangs. In other embodiments, the degree of complementarity is at least 60 percent, at least 70 percent, at least 80 percent, at least 90 percent, or even 100 percent.

Alternatively, nucleic acid stabilization can be accomplished via phosphate backbone modifications. Preferred stabilized nucleic acids of the instant invention have a modified backbone. It has been demonstrated that modification of the nucleic acid backbone provides enhanced activity of the nucleic acids when administered *in vivo*. One type of modified backbone is a phosphate backbone modification. Inclusion in immunostimulatory nucleic acids of at least two phosphorothioate linkages at the 5' end of the oligonucleotide and multiple (preferably five) phosphorothioate linkages at the 3' end, can in some circumstances provide maximal activity and protect the nucleic acid from degradation by intracellular exo- and endonucleases. Other modified nucleic acids include phosphodiester-modified nucleic acids, combinations of phosphodiester and phosphorothioate nucleic acids, alkylphosponate and arylphosphonate, alkylphosphorothioate and arylphosphorothioate, methylphosphonate,

methylphosphorothioate, phosphorodithioate, p-ethoxy, morpholino, and combinations thereof. Nucleic acids having phosphorothioate linkages provide maximal activity and protect the nucleic acid from degradation by intracellular exo- and endo-nucleases. and combinations thereof. Each of these combinations and their particular effects on immune cells is discussed in more detail with respect to CpG nucleic acids in issued U.S. Pat. Nos. 6,207,646 and 6,239,116, the entire contents of which are hereby incorporated by reference. It is believed that these modified nucleic acids may show more stimulatory activity due to enhanced nuclease resistance, increased cellular uptake, increased protein binding, and/or altered intracellular localization.

Modified backbones such as phosphorothioates may be synthesized using automated techniques employing either phosphoramidate or H-phosphonate chemistries. Aryl-and alkyl-phosphonates can be made, e.g.,. as described in U.S. Pat. No. 4,469,863; and alkylphosphotriesters (in which the charged oxygen moiety is alkylated as described in U.S. Pat. No. 5,023,243 and European Pat. No. 092,574) can be prepared by automated solid phase synthesis using commercially available reagents. Methods for making other DNA backbone modifications and substitutions have been described. Uhlmann E et al. (1990) *Chem Rev* 90:544; Goodchild J (1990) *Bioconjugate Chem* 1:165.

Other stabilized nucleic acids include: nonionic DNA analogs, such as alkyl- and aryl-phosphates (in which the charged phosphonate oxygen is replaced by an alkyl or aryl group), phosphodiester and alkylphosphotriesters, in which the charged oxygen moiety is alkylated. Nucleic acids which contain diol, such as tetraethyleneglycol or hexaethyleneglycol, at either or both termini have also been shown to be substantially resistant to nuclease degradation.

Another class of backbone modifications include 2'-O-methylribonucleosides (2'-OMe). These types of substitutions are described extensively in the prior art and in particular with respect to their immunostimulating properties in Zhao et al. (1999) *Bioorg Med Chem Lett* 9:24:3453-8. Zhao et al. describes methods of preparing 2'-OMe modifications to nucleic acids.

The immunostimulatory G,U-containing RNA oligomers of the invention are typically about 5 to about 40 nucleotides long. Thus in certain distinct embodiments, the G,U-containing RNA oligomer can be 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, or 40 nucleotides long. In one embodiment the G,U-containing RNA oligomer can be 5, 6, 7, 8, 9, 10, 11, 12, 13, 14,

15, 16, 17, 18, 19, or 20 nucleotides long. In one embodiment the G,U-containing RNA oligomer can be 5, 6, 7, 8, 9, 10, 11, or 12 nucleotides long. In one embodiment the G,U-containing RNA oligomer can be 8, 9, 10, 11, or 12 nucleotides long.

For example, RNA oligomers with the following base sequences have been discovered to be useful in the compositions and practice of the invention: 5'-GUGUUUAC-3'; 5'-GUAGGCAC-3'; 5'-CUAGGCAC-3'; 5'-CUCGGCAC-3'; and 5'-GUGUUUAC-3' in combination with 5'-GUAGGCAC-3'.

Because the immunostimulatory effects of the G,U-containing RNA oligomers of the invention have been discovered to be MyD88-dependent, it is the belief of the inventors that the immunostimulatory G,U-containing RNA oligomers of the invention may interact with at least one TLR as a step in exerting their immunostimulatory effect. The immunostimulatory G,U-containing RNA oligomers of the invention may thus represent or mimic at least portions of natural ligands for the at least one TLR. Such natural ligands may include ribosomal RNA, either prokaryotic or eukaryotic, as well as certain viral RNAs. The TLR or TLRs may be TLR8, TLR7, or some yet-to-be defined TLR. Natural ligands for TLR1, TLR7, TLR8, and TLR10 have not previously been described.

The immunostimulatory RNA molecules of the invention have been discovered to occur in nature in all types of RNA, usually in association with highly conserved sequence or key structural feature. In one example, immunostimulatory RNA has been discovered to occur in the context of an internal ribosome entry site (IRES).

An IRES is a minimal cis-acting RNA element contained within a complex structural feature in the 5′ untranslated region (5′ UTR) of viral RNA and other mRNAs that regulates the initiation of translation of the viral genome in a cap-independent manner. Hellen CU et al. (2001) *Genes Dev* 15:1593-1612. Cap-independent initiation of viral RNA translation was first observed in picornaviruses. Jackson RJ et al. (1990) *Trends Biochem Sci* 15:477-83; Jackson RJ et al. (1995) *RNA* 1:985-1000.

In most eukaryotic cells, mRNA translation initiation commences with recruitment of the cap binding complex eukaryotic initiation factor (eIF)4F, composed of eIF4E (cap binding protein), eIF4A, and eIF4G, to the 5′ capped end of the mRNA. The 40S ribosomal subunit, carrying eIF3, and the ternary initiator complex tRNA-eIF2-GTP are then recruited to the 5′ end of the mRNA through interaction between eIF3 and eIF4G. The 40S subunit then scans the mRNA in a 5′ to 3′ direction until it encounters an appropriate start codon,

whereupon the anticodon of initiator methionine-tRNA is engaged, the 60S subunit joins to form an 80S ribosome, and translation commences.

Thus the significance of an IRES, at least in the context of a virus, is believed to be the ability of the IRES to confer a selective advantage to the virus over usual cap-dependent translation in the cell.

The following viruses have been reported to have IRES elements in their genome: all picornaviruses; bovine viral diarrhea virus; classic swine fever virus; cricket paralysis virus; encephalomyocarditis virus; foot-and-mouth disease virus; Friend murine leukemia virus *gag* mRNA; HCV; human immunodeficiency virus *env* mRNA; Kaposi's sarcoma-associated herpesvirus; Moloney murine leukemia virus *gag* mRNA; *Plautia stali* intestine virus; poliovirus; rhinovirus; *Rhopalosiphum padi* virus; and Rous sarcoma virus. Hellen CU et al. (2001) *Genes Dev* 15:1593-1612. This list is not intended to be limiting.

The viral proteins of hepatitis C virus (HCV) are translated from a 9.5 kb single-stranded positive sense RNA which is flanked by 5′ and 3′ UTRs. The highly conserved 5′ UTR includes an IRES present in nt 40-370. Reynolds JE et al. (1996) *RNA* 2:867-78. The HCV 5′ UTR is believed to have four major structural domains (I-IV), of which domains II and III have subdomains. Subdomain IIId includes a 27 nt stem-loop (nt 253-279) that on the basis of in vivo mutational studies has been reported to be critical in HCV IRES-mediated translation. Kieft JS et al. (1999) *J Mol Biol* 292:513-29; Klinck R et al. (2000) *RNA* 6:1423-31. The sequence of the IIId 27-mer is provided by 5′-GCCGA<u>GUAGU</u>GUUGGGUCGCGAAAGGC-3′ (SEQ ID NO:4), wherein the UUGGGU forms the terminal loop. The stem-loop structure is reported to include a number of non-Watson—Crick base pairs, typical of other RNAs, including wobble U∘G, U∘A, G∘A, and A∘A base pairs.

As another example, the immunostimulatory RNA sequences of the invention have been discovered to occur in G,U-rich sequence near the 5′ end of the viral RNA of human immunodeficiency virus type 1 (HIV-1) that is crucial to efficient viral RNA packaging. Russell RS et al. (2002) *Virology* 303:152-63. Specifically, two key G,U-rich sequences within U5, namely 5′-GUAGUGUGUG-3′ (SEQ ID NO:2) and 5′-GUCUGUUGUGUG-3′ (SEQ ID NO:3), corresponding to nt 99-108 and 112-123 of strain BH10, respectively, have been found according to the present invention to be highly immunostimulatory (see Example

11 below). It will be noted that SEQ ID NO:2 includes both GUAGU and GUGUG, and SEQ ID NO:3 includes GUGUG.

As yet another example, the immunostimulatory RNA sequences of the invention have been found to occur in 5S ribosomal RNA loop E of a large number of species of bacteria.

TLR8 and TLR7 show high sequence homology to TLR9 (**FIG. 8**). TLR9 is the CpG-DNA receptor and transduces immunostimulatory signals. Two DNA binding motifs have been described in TLR9 (U.S. Pat. Application No. 09/954,987) that are also present in TLR8 and TLR7 with some modifications (**FIG. 9**). Despite this similarity, however, TLR7 and TLR8 do not bind CpG-DNA.

It has been discovered according to the present invention that guanosine, particularly guanosine in combination with uracil, and certain guanosine-containing nucleic acids and derivatives thereof, are natural ligands of TLR8. It has been discovered according to the present invention that RNA, oxidized RNA, G,U-rich nucleic acids, and at least partially double-stranded nucleic acid molecules having at least one G-U base pair are TLR8 ligands. In certain preferred embodiments involving guanosine, guanosine derivatives, and G,U-rich nucleic acids, guanosine is the ribonucleoside. Nucleic acid molecules containing GUU, GUG, GGU, GGG, UGG, UGU, UUG, UUU, multiples and any combinations thereof are believed to be TLR8 ligands. In some embodiments the TLR8 ligand is a G,U-rich oligonucleotide that includes a hexamer sequence $(UUGUGG)_n$, $(UGGUUG)_n$, $(GUGUGU)_n$, or $(GGGUUU)_n$ where n is an integer from 1 to 8, and preferably n is at least 3. In addition, it has also been discovered according to the present invention that mixtures of ribonucleoside vanadyl complexes (i.e., mixtures of adenine, cytosine, guanosine, and uracil ribonucleoside vanadyl complexes), and guanosine ribonucleoside vanadyl complexes alone, are TLR8 ligands. In addition, it has been discovered according the present invention that certain imidazoquinolines, including resiquimod and imiquimod, are TLR8 ligands.

It has also been discovered according to the present invention that guanosine, and certain guanosine-containing nucleic acids and derivatives thereof, are natural ligands of TLR7. It has been discovered according to the present invention that RNA, oxidized RNA, G-rich nucleic acids, and at least partially double-stranded nucleic acid molecules that are rich in G content are TLR7 ligands. In certain preferred embodiments involving guanosine, guanosine derivatives, and G-rich nucleic acids, guanosine is the ribonucleoside. In addition,

it has also been discovered according to the present invention that mixtures of ribonucleoside vanadyl complexes (i.e., mixtures of adenine, cytosine, guanosine, and uracil ribonucleoside vanadyl complexes), and guanosine ribonucleoside vanadyl complexes alone, are TLR7 ligands. In addition, it has been discovered according the present invention that 7-allyl-8-oxoguanosine (loxoribine) is a TLR7 ligand.

In addition to having diverse ligands, the various TLRs are believed to be differentially expressed in various tissues and on various types of immune cells. For example, human TLR7 has been reported to be expressed in placenta, lung, spleen, lymph nodes, tonsil and on plasmacytoid precursor dendritic cells (pDCs). Chuang T-H et al. (2000) *Eur Cytokine Netw* 11:372-8); Kadowaki N et al. (2001) *J Exp Med* 194:863-9. Human TLR8 has been reported to be expressed in lung, peripheral blood leukocytes (PBL), placenta, spleen, lymph nodes, and on monocytes. Kadowaki N et al. (2001) *J Exp Med* 194:863-9; Chuang T-H et al. (2000) *Eur Cytokine Netw* 11:372-8. Human TLR9 is reportedly expressed in spleen, lymph nodes, bone marrow, PBL, and on pDCs, B cells, and CD123+ DCs. Kadowaki N et al. (2001) *J Exp Med* 194:863-9; Bauer S et al. (2001) *Proc Natl Acad Sci USA* 98:9237-42; Chuang T-H et al. (2000) *Eur Cytokine Netw* 11:372-8.

Guanosine derivatives have previously been described as B-cell and NK cell activators, but their receptors and mechanism of action were not understood. Goodman MG et al. (1994) *J Pharm Exp Ther* 274:1552-57; Reitz AB et al. (1994) *J Med Chem* 37:3561-78. Such guanosine derivatives include, but are not limited to, 8-bromoguanosine, 8-oxoguanosine, 8-mercaptoguanosine, and 7-allyl-8-oxoguanosine (loxoribine).

Imidazoquinolines are synthetic small molecule immune response modifiers thought to induce expression of several cytokines including interferons (e.g., IFN-α and IFN-γ), tumor necrosis factor alpha (TNF-α) and some interleukins (e.g., IL-1, IL-6 and IL-12). Imidazoquinolines are capable of stimulating a Th1 immune response, as evidenced in part by their ability to induce increases in IgG2a levels. Imidazoquinoline agents reportedly are also capable of inhibiting production of Th2 cytokines such as IL-4, IL-5, and IL-13. Some of the cytokines induced by imidazoquinolines are produced by macrophages and dendritic cells. Some species of imidazoquinolines have been reported to increase NK cell lytic activity and to stimulate B-cell proliferation and differentiation, thereby inducing antibody production and secretion.

As used herein, an imidazoquinoline agent includes imidazoquinoline amines, imidazopyridine amines, 6,7-fused cycloalkylimidazopyridine amines, and 1,2 bridged imidazoquinoline amines. These compounds have been described in U.S. Pat. Nos. 4689338, 4929624, 5238944, 5266575, 5268376, 5346905, 5352784, 5389640, 5395937, 5494916, 5482936, 5525612, 6039969 and 6110929. Particular species of imidazoquinoline agents include 4-amino-α,α-dimethyl-2-ethoxymethyl-1*H*-imidazo[4,5-c]quinoline-1-ethanol (resiquimod or R-848 or S-28463; PCT/US01/28764, WO 02/22125); and 1-(2-methylpropyl)-1*H*-imidazo[4,5-c]quinoline-4-amine (imiquimod or R-837 or S-26308). Imiquimod is currently used in the topical treatment of warts such as genital and anal warts and has also been tested in the topical treatment of basal cell carcinoma.

Nucleotide and amino acid sequences of human and murine TLR3 are known. See, for example, GenBank Accession Nos. U88879, NM_003265, NM_126166, AF355152; and AAC34134, NP_003256, NP_569054, AAK26117. Human TLR3 is reported to be 904 amino acids long and to have a sequence provided in SEQ ID NO:20. A corresponding nucleotide sequence is provided as SEQ ID NO:21. Murine TLR3 is reported to be 905 amino acids long and to have a sequence as provided in SEQ ID NO:22. A corresponding nucleotide sequence is provided as SEQ ID NO:23. TLR3 polypeptide includes an extracellular domain having leucine-rich repeat region, a transmembrane domain, and an intracellular domain that includes a TIR domain.

As used herein a "TLR3 polypeptide" refers to a polypeptide including a full-length TLR3 according to one of the sequences above, orthologs, allelic variants, SNPs, variants incorporating conservative amino acid substitutions, TLR3 fusion proteins, and functional fragments of any of the foregoing. Preferred embodiments include human TLR3 polypeptides having at least 65 percent sequence identity, more preferably at least 80 percent sequence identity, even more preferably with at least 90 percent sequence identity, and most preferably with at least 95 percent sequence identity with the human TLR3 amino acid sequence of SEQ ID NO:20. Preferred embodiments also include murine TLR3 polypeptides having at least 65 percent sequence identity, more preferably at least 80 percent sequence identity, even more preferably with at least 90 percent sequence identity, and most preferably with at least 95 percent sequence identity with the murine TLR3 amino acid sequence of SEQ ID NO:22.

As used herein "TLR3 signaling" refers to an ability of a TLR3 polypeptide to activate the TLR/IL-1R (TIR) signaling pathway, also referred to herein as the TLR signal transduction pathway. Changes in TLR3 activity can be measured by assays such as those disclosed herein, including expression of genes under control of κB-sensitive promoters and enhancers. Such naturally occurring genes include the genes encoding IL-1β, IL-6, IL-8, the p40 subunit of interleukin 12 (IL-12 p40), and the costimulatory molecules CD80 and CD86. Other genes can be placed under the control of such regulatory elements (see below) and thus serve to report the level of TLR3 signaling. Additional nucleotide sequence can be added to SEQ ID NO:21 or SEQ ID NO:23, preferably to the 5' or the 3' end of the open reading frame of SEQ ID NO:21, to yield a nucleotide sequence encoding a chimeric polypeptide that includes a detectable or reporter moiety, e.g., FLAG, luciferase (luc), green fluorescent protein (GFP), and others known by those skilled in the art.

SEQ ID NO:20 Human TLR3 amino acid

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MRQTLPCIYF WGGLLPFGML CASSTTKCTV SHEVADCSHL KLTQVPDDLP TNITVLNLTH   60
NQLRRLPAAN FTRYSQLTSL DVGFNTISKL EPELCQKLPM LKVLNLQHNE LSQLSDKTFA  120
FCTNLTELHL MSNSIQKIKN NPFVKQKNLI TLDLSHNGLS STKLGTQVQL ENLQELLLSN  180
NKIQALKSEE LDIFANSSLK KLELSSNQIK EFSPGCFHAI GRLFGLFLNN VQLGPSLTEK  240
LCLELANTSI RNLSLSNSQL STTSNTTFLG LKWTNLTMLD LSYNNLNVVG NDSFAWLPQL  300
EYFFLEYNNI QHLFSHSLHG LFNVRYLNLK RSFTKQSISL ASLPKIDDFS FQWLKCLEHL  360
NMEDNDIPGI KSNMFTGLIN LKYLSLSNSF TSLRTLTNET FVSLAHSPLH ILNLTKNKIS  420
KIESDAFSWL GHLEVLDLGL NEIGQELTGQ EWRGLENIFE IYLSYNKYLQ LTRNSFALVP  480
SLQRLMLRRV ALKNVDSSPS PFQPLRNLTI LDLSNNNIAN INDDMLEGLE KLEILDLQHN  540
NLARLWKHAN PGGPIYFLKG LSHLHILNLE SNGFDEIPVE VFKDLFELKI IDLGLNNLNT  600
LPASVFNNQV SLKSLNLQKN LITSVEKKVF GPAFRNLTEL DMRFNPFDCT CESIAWFVNW  660
INETHTNIPE LSSHYLCNTP PHYHGFPVRL FDTSSCKDSA PFELFFMINT SILLIFIFIV  720
LLIHFEGWRI SFYWNVSVHR VLGFKEIDRQ TEQFEYAAYI IHAYKDKDWV WEHFSSMEKE  780
DQSLKFCLEE RDFEAGVFEL EAIVNSIKRS RKIIFVITHH LLKDPLCKRF KVHHAVQQAI  840
EQNLDSIILV FLEEIPDYKL NHALCLRRGM FKSHCILNWP VQKERIGAFR HKLQVALGSK  900
NSVH                                                               904
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SEQ ID NO:21 Human TLR3 nucleotide

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cactttcgag agtgccgtct atttgccaca cacttccctg atgaaatgtc tggatttgga   60
ctaaagaaaa aaggaaaggc tagcagtcat ccaacagaat catgagacag actttgcctt  120
gtatctactt ttgggggggc cttttgccct ttgggatgct gtgtgcatcc tccaccacca  180
agtgcactgt tagccatgaa gttgctgact gcagccacct gaagttgact caggtacccg  240
atgatctacc cacaaacata acagtgttga accttaccca taatcaactc agaagattac  300
cagccgccaa cttcacaagg tatagccagc taactagctt ggatgtagga tttaacacca  360
tctcaaaact ggagccagaa ttgtgccaga aacttcccat gttaaaagtt ttgaacctcc  420
agcacaatga gctatctcaa ctttctgata aaacctttgc cttctgcacg aatttgactg  480
aactccatct catgtccaac tcaatccaga aaattaaaaa taatcccttt gtcaagcaga  540
agaatttaat cacattagat ctgtctcata atggcttgtc atctacaaaa ttaggaactc  600
aggttcagct ggaaaatctc caagagcttc tattatcaaa caataaaatt caagcgctaa  660
aaagtgaaga actggatatc tttgccaatt catctttaaa aaaattagag ttgtcatcga  720
atcaaattaa agagttttct ccagggtgtt ttcacgcaat tggaagatta tttggcctct  780
ttctgaacaa tgtccagctg ggtcccagcc ttacagagaa gctatgtttg gaattagcaa  840
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acacaagcat tcggaatctg tctctgagta acagccagct gtccaccacc agcaatacaa  900
ctttcttggg actaaagtgg acaaatctca ctatgctcga tctttcctac aacaacttaa  960
atgtggttgg taacgattcc tttgcttggc ttccacaact agaatatttc ttcctagagt 1020
ataataatat acagcatttg ttttctcact ctttgcacgg gcttttcaat gtgaggtacc 1080
tgaatttgaa acggtctttt actaaacaaa gtatttccct tgcctcactc cccaagattg 1140
atgatttttc ttttcagtgg ctaaaatgtt tggagcacct taacatggaa gataatgata 1200
ttccaggcat aaaaagcaat atgttcacag gattgataaa cctgaaatac ttaagtctat 1260
ccaactcctt tacaagtttg cgaactttga caaatgaaac atttgtatca cttgctcatt 1320
ctcccttaca catactcaac ctaaccaaga ataaaatctc aaaaatagag agtgatgctt 1380
tctcttggtt gggccaccta gaagtacttg acctgggcct taatgaaatt gggcaagaac 1440
tcacaggcca ggaatggaga ggtctagaaa atattttcga aatctatctt tcctacaaca 1500
agtacctgca gctgactagg aactcctttg ccttggtccc aagccttcaa cgactgatgc 1560
tccgaagggt ggcccttaaa aatgtggata gctctccttc accattccag cctcttcgta 1620
acttgaccat tctggatcta agcaacaaca acatagccaa cataaatgat gacatgttgg 1680
agggtcttga gaaactagaa attctcgatt tgcagcataa caacttagca cggctctgga 1740
aacacgcaaa ccctggtggt cccatttatt tcctaaaggg tctgtctcac ctccacatcc 1800
ttaacttgga gtccaacggc tttgacgaga tcccagttga ggtcttcaag gatttatttg 1860
aactaaagat catcgattta ggattgaata atttaaacac acttccagca tctgtcttta 1920
ataatcaggt gtctctaaag tcattgaacc ttcagaagaa tctcataaca tccgttgaga 1980
agaaggtttt cgggccagct ttcaggaacc tgactgagtt agatatgcgc tttaatccct 2040
ttgattgcac gtgtgaaagt attgcctggt ttgttaattg gattaacgag acccatacca 2100
acatccctga gctgtcaagc cactaccttt gcaacactcc acctcactat catgggttcc 2160
cagtgagact tttgatacaa tcatcttgca aagacagtgc cccctttgaa ctctttttca 2220
tgatcaatac cagtatcctg ttgattttta tctttattgt acttctcatc cactttgagg 2280
gctggaggat atctttttat tggaatgttt cagtacatcg agttcttggt ttcaaagaaa 2340
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aggattgggt ctgggaacat ttctcttcaa tggaaaagga agaccaatct ctcaaatttt 2460
gtctggaaga aagggacttt gaggcgggtg tttttgaact agaagcaatt gttaacagca 2520
tcaaaagaag cagaaaaatt atttttgtta taacacacca tctattaaaa gacccattat 2580
gcaaaagatt caaggtacat catgcagttc aacaagctat tgaacaaaat ctggattcca 2640
ttatattggt tttccttgag gagattccag attataaact gaaccatgca ctctgtttgc 2700
gaagaggaat gtttaaatct cactgcatct tgaactggcc agttcagaaa gaacggatag 2760
gtgcctttcg tcataaattg caagtagcac ttggatccaa aaactctgta cattaaattt 2820
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ttaagttttc cataaaggtg ttataatttg tttattcata tttgtaaatg attatattct 2940
atcacaatta catctcttct aggaaaatgt gtctccttat ttcaggccta tttttgacaa 3000
ttgacttaat ttacccaaa ataaaacata taagcacgta aaaaaaaaaa aaaaaaa    3057
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SEQ ID NO:22 Murine TLR3 amino acid

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MKGCSSYLMY SFGGLLSLWI LLVSSTNQCT VRYNVADCSH LKLTHIPDDL PSNITVLNLT   60
HNQLRRLPPT NFTRYSQLAI LDAGFNSISK LEPELCQILP LLKVLNLQHN ELSQISDQTF  120
VFCTNLTELD LMSNSIHKIK SNPFKNQKNL IKLDLSHNGL SSTKLGTGVQ LENLQELLLA  180
KNKILALRSE ELEFLGNSSL RKLDLSSNPL KEFSPGCFQT IGKLFALLLN NAQLNPHLTE  240
KLCWELSNTS IQNLSLANNQ LLATSESTFS GLKWTNLTQL DLSYNNLHDV GNGSFSYLPS  300
LRYLSLEYNN IQRLSPRSFY GLSNLRYLSL KRAFTKQSVS LASHPNIDDF SFQWLKYLEY  360
LNMDDNNIPS TKSNTFTGLV SLKYLSLSKT FTSLQTLTNE TFVSLAHSPL LTLNLTKNHI  420
SKIANGTFSW LGQLRILDLG LNEIEQKLSG QEWRGLRNIF EIYLSYNKYL QLSTSSFALV  480
PSLQRLMLRR VALKNVDISP SPFRPLRNLT ILDLSNNNIA NINEDLLEGL ENLEILDFQH  540
NNLARLWKRA NPGGPVNFLK GLSHLHILNL ESNGLDEIPV GVFKNLFELK SINLGLNNLN  600
KLEPFIFDDQ TSLRSLNLQK NLITSVEKDV FGPPFQNLNS LDMRFNPFDC TCESISWFVN  660
WINQTHTNIF ELSTHYLCNT PHHYYGFPLK LFDTSSCKDS APFELLFIIS TSMLLVFILV  720
VLLIHIEGWR ISFYWNVSVH RILGFKEIDT QAEQFEYTAY IIHAHKDRDW VWEHFSPMEE  780
QDQSLKFCLE ERDFEAGVLG LEAIVNSIKR SRKIIFVITH HLLKDPLCRR FKVHHAVQQA  840
IEQNLDSIIL IFLQNIPDYK LNHALCLRRG MFKSHCILNW PVQKERINAF HHKLQVALGS  900
RNSAH                                                            904
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SEQ ID NO:23 Murine TLR3 nucleotide

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tagaatatga tacagggatt gcacccataa tctgggctga atcatgaaag ggtgttcctc   60
ttatctaatg tactcctttg ggggactttt gtccctatgg attcttctgg tgtcttccac  120
aaaccaatgc actgtgagat acaacgtagc tgactgcagc catttgaagc taacacacat  180
acctgatgat cttccctcta acataacagt gttgaatctt actcacaacc aactcagaag  240
attaccacct accaacttta caagatacag ccaacttgct atcttggatg caggatttaa  300
ctccatttca aaactggagc cagaactgtg ccaaatactc cctttgttga aagtattgaa  360
cctgcaacat aatgagctct ctcagatttc tgatcaaacc tttgtcttct gcacgaacct  420
gacagaactc gatctaatgt ctaactcaat acacaaaatt aaaagcaacc ctttcaaaaa  480
ccagaagaat ctaatcaaat tagatttgtc tcataatggt ttatcatcta caaagttggg  540
aacgggggtc caactggaga acctccaaga actgctctta gcaaaaaata aaatccttgc  600
gttgcgaagt gaagaacttg agtttcttgg caattcttct ttacgaaagt tggacttgtc  660
atcaaatcca cttaaagagt tctccccggg gtgtttccag acaattggca agttattcgc  720
cctcctcttg aacaacgccc aactgaaccc ccacctcaca gagaagcttt gctgggaact  780
ttcaaacaca agcatccaga atctctctct ggctaacaac cagctgctgg ccaccagcga  840
gagcactttc tctgggctga agtggacaaa tctcacccag ctcgatcttt cctacaacaa  900
cctccatgat gtcggcaacg gttccttctc ctatctccca agcctgaggt atctgtctct  960
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gtacctgagt ttgaagcgag catttactaa gcaaagtgtt tcacttgctt cacatcccaa 1080
cattgacgat ttttcctttc aatggttaaa atatttggaa tatctcaaca tggatgacaa 1140
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gatgctcagg agggtggccc ttaaaaatgt ggatatctcc ccttcacctt tccgccctct 1560
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gctggagggt cttgagaatc tagaaatcct ggattttcag cacaataact tagccaggct 1680
ctggaaacgc gcaaaccccg gtggtcccgt taatttcctg aaggggctgt ctcacctcca 1740
catcttgaat ttagagtcca acggcttaga tgaaatccca gtcggggttt tcaagaactt 1800
attcgaacta aagagcatca atctaggact gaataactta aacaaacttg aaccattcat 1860
ttttgatgac cagacatctc taaggtcact gaacctccag aagaacctca taacatctgt 1920
tgagaaggat gttttcgggc cgccttttca aaacctgaac agtttagata tgcgcttcaa 1980
tccgttcgac tgcacgtgtg aaagtatttc ctggtttgtt aactggatca accagaccca 2040
cactaatatc tttgagctgt ccactcacta cctctgtaac actccacatc attattatgg 2100
cttcccccctg aagcttttcg atacatcatc ctgtaaagac agcgccccct ttgaactcct 2160
cttcataatc agcaccagta tgctcctggt ttttatactt gtggtactgc tcattcacat 2220
cgagggctgg aggatctctt tttactggaa tgtttcagtg catcggattc ttggtttcaa 2280
ggaaatagac acacaggctg agcagtttga atatacagcc tacataattc atgcccataa 2340
agacagagac tgggtctggg aacatttctc cccaatggaa gaacaagacc aatctctcaa 2400
attttgccta gaagaaaggg actttgaagc aggcgtcctt ggacttgaag caattgttaa 2460
tagcatcaaa agaagccgaa aaatcatttt cgttatcaca caccatttat taaaagaccc 2520
tctgtgcaga agattcaagg tacatcacgc agttcagcaa gctattgagc aaaatctgga 2580
ttcaattata ctgatttttc tccagaatat tccagattat aaactaaacc atgcactctg 2640
tttgcgaaga ggaatgttta aatctcattg catcttgaac tggccagttc agaaagaacg 2700
gataaatgcc tttcatcata aattgcaagt agcacttgga tctcggaatt cagcacatta 2760
aactcatttg aagatttgga gtcggtaaag ggatagatcc aatttataaa ggtccatcat 2820
gaatctaagt tttacttgaa agttttgtat atttatttat atgtatagat gatgatatta 2880
catcacaatc caatctcagt tttgaaatat ttcggcttat ttcattgaca tctggtttat 2940
tcactccaaa taaacacatg ggcagttaaa aacatcctct attaatagat tacccattaa 3000
ttcttgaggt gtatcacagc tttaaagggt tttaaatatt tttatataaa taagactgag 3060
agttttataa atgtaatttt ttaaaactcg agtcttactg tgtagctcag aaaggcctgg 3120
aaattaatat attagagagt catgtcttga acttatttat ctctgcctcc ctctgtctcc 3180
agagtgttgc ttttaagggc atgtagcacc acacccagct atgtacgtgt gggattttat 3240
aatgctcatt tttgagacgt ttatagaata aaagataatt gcttttatgg tataaggcta 3300
cttgaggtaa                                                       3310
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Nucleotide and amino acid sequences of human and murine TLR7 are known. See, for example, GenBank Accession Nos. AF240467, AF245702, NM_016562, AF334942, NM_133211; and AAF60188, AAF78035, NP_057646, AAL73191, AAL73192. Human TLR7 is reported to be 1049 amino acids long and to have a sequence provided in SEQ ID NO:24. A corresponding nucleotide sequence is provided as SEQ ID NO:25. Murine TLR7 is reported to be 1050 amino acids long and to have a sequence as provided in SEQ ID NO:26. A corresponding nucleotide sequence is provided as SEQ ID NO:27. TLR7 polypeptide includes an extracellular domain having leucine-rich repeat region, a transmembrane domain, and an intracellular domain that includes a TIR domain.

As used herein a "TLR7 polypeptide" refers to a polypeptide including a full-length TLR7 according to one of the sequences above, orthologs, allelic variants, SNPs, variants incorporating conservative amino acid substitutions, TLR7 fusion proteins, and functional fragments of any of the foregoing. Preferred embodiments include human TLR7 polypeptides having at least 65 percent sequence identity, more preferably at least 80 percent sequence identity, even more preferably with at least 90 percent sequence identity, and most preferably with at least 95 percent sequence identity with the human TLR7 amino acid sequence of SEQ ID NO:24. Preferred embodiments also include murine TLR7 polypeptides having at least 65 percent sequence identity, more preferably at least 80 percent sequence identity, even more preferably with at least 90 percent sequence identity, and most preferably with at least 95 percent sequence identity with the murine TLR7 amino acid sequence of SEQ ID NO:26.

As used herein "TLR7 signaling" refers to an ability of a TLR7 polypeptide to activate the TLR/IL-1R (TIR) signaling pathway, also referred to herein as the TLR signal transduction pathway. Changes in TLR7 activity can be measured by assays such as those disclosed herein, including expression of genes under control of κB-sensitive promoters and enhancers. Such naturally occurring genes include the genes encoding IL-1β, IL-6, IL-8, the p40 subunit of interleukin 12 (IL-12 p40), and the costimulatory molecules CD80 and CD86. Other genes can be placed under the control of such regulatory elements (see below) and thus serve to report the level of TLR7 signaling. Additional nucleotide sequence can be added to SEQ ID NO:25 or SEQ ID NO:27, preferably to the 5' or the 3' end of the open reading frame of SEQ ID NO:25, to yield a nucleotide sequence encoding a chimeric polypeptide that

includes a detectable or reporter moiety, e.g., FLAG, luciferase (luc), green fluorescent protein (GFP), and others known by those skilled in the art.

SEQ ID NO:24 Human TLR7 amino acid

```
MVFPMWTLKR QILILFNIIL ISKLLGARWF PKTLPCDVTL DVPKNHVIVD CTDKHLTEIP   60
GGIPTNTTNL TLTINHIPDI SPASFHRLDH LVEIDFRCNC VPIPLGSKNN MCIKRLQIKP  120
RSFSGLTYLK SLYLDGNQLL EIPQGLPPSL QLLSLEANNI FSIRKENLTE LANIEILYLG  180
QNCYYRNPCY VSYSIEKDAF LNLTKLKVLS LKDNNVTAVP TVLPSTLTEL YLYNNMIAKI  240
QEDDFNNLNQ LQILDLSGNC PRCYNAPFPC APCKNNSPLQ IPVNAFDALT ELKVLRLHSN  300
SLQHVPPRWF KNINKLQELD LSQNFLAKEI GDAKFLHFLP SLIQLDLSFN FELQVYRASM  360
NLSQAFSSLK SLKILRIRGY VFKELKSFNL SPLHNLQNLE VLDLGTNFIK IANLSMFKQF  420
KRLKVIDLSV NKISPSGDSS EVGFCSNART SVESYEPQVL EQLHYFRYDK YARSCRFKNK  480
EASFMSVNES CYKYGQTLDL SKNSIFFVKS SDFQHLSFLK CLNLSGNLIS QTLNGSEFQP  540
LAELRYLDFS NNRLDLLHST AFEELHKLEV LDISSNSHYF QSEGITHMLN FTKNLKVLQK  600
LMMNDNDISS STSRTMESES LRTLEFRGNH LDVLWREGDN RYLQLFKNLL KLEELDISKN  660
SLSFLPSGVF DGMPPNLKNL SLAKNGLKSF SWKKLQCLKN LETLDLSHNQ LTTVPERLSN  720
CSRSLKNLIL KNNQIRSLTK YFLQDAFQLR YLDLSSNKIQ MIQKTSFPEN VLNNLKMLLL  780
HHNRFLCTCD AVWFVWWVNH TEVTIPYLAT DVTCVGPGAH KGQSVISLDL YTCELDLTNL  840
ILFSLSISVS LFLMVMMTAS HLYFWDVWYI YHFCKAKIKG YQRLISPDCC YDAFIVYDTK  900
DPAVTEWVLA ELVAKLEDPR EKHFNLCLEE RDWLPGQPVL ENLSQSIQLS KKTVFVMTDK  960
YAKTENFKIA FYLSHQRLMD EKVDVIILIF LEKPFQKSKF LQLRKRLCGS SVLEWPTNPQ 1020
AHPYFWQCLK NALATDNHVA YSQVFKETV                                  1049
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SEQ ID NO:25 Human TLR7 nucleotide

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actccagata taggatcact ccatgccatc aagaaagttg atgctattgg gcccatctca   60
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ggaagaagac taaaaatggt gtttccaatg tggacactga agagacaaat tcttatcctt  180
tttaacataa tcctaatttc caaactcctt ggggctagat ggtttcctaa aactctgccc  240
tgtgatgtca ctctggatgt tccaaagaac catgtgatcg tggactgcac agacaagcat  300
ttgacagaaa ttcctggagg tattcccacg aacaccacga acctcaccct caccattaac  360
cacataccag acatctcccc agcgtccttt cacagactgg accatctggt agagatcgat  420
ttcagatgca actgtgtacc tattccactg gggtcaaaaa acaacatgtg catcaagagg  480
ctgcagatta aacccagaag ctttagtgga ctcacttatt taaaatccct ttacctggat  540
ggaaaccagc tactagagat accgcagggc ctcccgccta gcttacagct tctcagcctt  600
gaggccaaca acatcttttc catcagaaaa gagaatctaa cagaactggc caacatagaa  660
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gagaaagatg ccttcctaaa cttgacaaag ttaaaagtgc tctccctgaa agataacaat  780
gtcacagccg tccctactgt tttgccatct actttaacag aactatatct ctacaacaac  840
atgattgcaa aaatccaaga agatgatttt aataacctca accaattaca aattcttgac  900
ctaagtggaa attgccctcg ttgttataat gccccatttc cttgtgcgcc gtgtaaaaat  960
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ctccaggaac tggatctgtc ccaaaacttc ttggccaaag aaattgggga tgctaaattt 1140
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agtgaattcc aacctttagc agagctgaga tatttggact tctccaacaa ccggcttgat 1800
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aaggttctgc agaaactgat gatgaacgac aatgacatct cttcctccac cagcaggacc 1980
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gccaactatt tcacaacttc tgtaagc                                     5007
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SEQ ID NO:26 Murine TLR7 amino acid

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MVFSMWTRKR QILIFLNMLL VSRVFGFRWF PKTLPCEVKV NIPEAHVIVD CTDKHLTEIP  60
EGIPTNTTNL TLTINHIPSI SPDSFRRLNH LEEIDLRCNC VPVLLGSKAN VCTKRLQIRP 120
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GSFSGLSDLK ALYLDGNQLL EIPQDLPSSL HLLSLEANNI FSITKENLTE LVNIETLYLG  180
QNCYYRNPCN VSYSIEKDAF LVMRNLKVLS LKDNNVTAVP TTLPPNLLEL YLYNNIIKKI  240
QENDFNNLNE LQVLDLSGNC PRCYNVPYPC TPCENNSPLQ IHDNAFNSLT ELKVLRLHSN  300
SLQHVPPTWF KNMRNLQELD LSQNYLAREI EEAKFLHFLP NLVELDFSFN YELQVYHASI  360
TLPHSLSSLE NLKILRVKGY VFKELKNSSL SVLHKLPRLE VLDLGTNFIK IADLNIFKHF  420
ENLKLIDLSV NKISPSEESR EVGFCPNAQT SVDRHGPQVL EALHYFRYDE YARSCRFKNK  480
EPPSFLPLNA DCHIYGQTLD LSRNNIFFIK PSDFQHLSFL KCLNLSGNTI GQTLNGSELW  540
PLRELRYLDF SNNRLDLLYS TAFEELQSLE VLDLSSNSHY FQAEGITHML NFTKKLRLLD  600
KLMMNDNDIS TSASRTMESD SLRILEFRGN HLDVLWRAGD NRYLDFFKNL FNLEVLDISR  660
NSLNSLPPEV FEGMPPNLKN LSLAKNGLKS FFWDRLQLLK HLEILDLSHN QLTKVPERLA  720
NCSKSLTTLI LKHNQIRQLT KYFLEDALQL RYLDISSNKI QVIQKTSFPE NVLNNLEMLV  780
LHHNRFLCNC DAVWFVWWVN HTDVTIPYLA TDVTCVGPGA HKGQSVISLD LYTCELDLTN  840
LILFSVSISS VLFLMVVMTT SHLFFWDMWY IYYFWKAKIK GYQHLQSMES CYDAFIVYDT  900
KNSAVTEWVL QELVAKLEDP REKHFNLCLE ERDWLPGQPV LENLSQSIQL SKKTVFVMTQ  960
KYAKTESFKM AFYLSHQRLL DEKVDVIILI FLEKPLQKSK FLQLRKRLCR SSVLEWPANP 1020
QAHPYFWQCL KNALTTDNHV AYSQMFKETV                                 1050
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SEQ ID NO:27 Murine TLR7 nucleotide

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tttgggtttc gatggtttcc taaaactcta ccttgtgaag ttaaagtaaa tatcccagag  180
gcccatgtga tcgtggactg cacagacaag catttgacag aaatccctga gggcattccc  240
actaacacca ccaatcttac ccttaccatc aaccacatac caagcatctc tccagattcc  300
ttccgtaggc tgaaccatct ggaagaaatc gatttaagat gcaattgtgt acctgttcta  360
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gatctgccat ccagcttaca tcttctgagc cttgaggcta acaacatctt ctccatcacg  540
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cctaatttac tagagctcta tctttataac aatatcatta agaaaatcca agaaaatgat  780
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aatgtcccat atccgtgtac accgtgtgaa aataattccc ccttacagat ccatgacaat  900
gctttcaatt cattgacaga attaaaagtt ttacgtttac acagtaattc tcttcagcat  960
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cgctttcttt gcaactgtga tgctgtgtgg tttgtctggt gggttaacca tacagatgtt 2460
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atgttcaagg aaacagtcta gctctctgaa gaatgtcacc acctaggaca tgccttgaat 3240
cga                                                               3243
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Nucleotide and amino acid sequences of human and murine TLR8 are known. See, for example, GenBank Accession Nos. AF246971, AF245703, NM_016610, XM_045706, AY035890, NM_133212; and AAF64061, AAF78036, NP_057694, XP_045706, AAK62677, NP_573475. Human TLR8 is reported to exist in at least two isoforms, one 1041 amino acids long having a sequence provided in SEQ ID NO:28, and the other 1059 amino acids long having a sequence as provided in SEQ ID NO:30. Corresponding nucleotide sequences are provided as SEQ ID NO:29 and SEQ ID NO:31, respectively. The shorter of these two isoforms is believed to be more important. Murine TLR8 is 1032 amino acids long and has a sequence as provided in SEQ ID NO:32. The corresponding nucleotide sequence is provided as SEQ ID NO:33. TLR8 polypeptide includes an extracellular domain having leucine-rich repeat region, a transmembrane domain, and an intracellular domain that includes a TIR domain.

As used herein a "TLR8 polypeptide" refers to a polypeptide including a full-length TLR8 according to one of the sequences above, orthologs, allelic variants, SNPs, variants incorporating conservative amino acid substitutions, TLR8 fusion proteins, and functional fragments of any of the foregoing. Preferred embodiments include human TLR8 polypeptides having at least 65 percent sequence identity, more preferably at least 80 percent sequence identity, even more preferably with at least 90 percent sequence identity, and most preferably with at least 95 percent sequence identity with the human TLR8 amino acid sequence of SEQ ID NO:28. Preferred embodiments also include murine TLR8 polypeptides having at least 65 percent sequence identity, more preferably at least 80 percent sequence identity, even more preferably with at least 90 percent sequence identity, and most preferably

with at least 95 percent sequence identity with the murine TLR8 amino acid sequence of SEQ ID NO:32.

As used herein "TLR8 signaling" refers to an ability of a TLR8 polypeptide to activate the TLR/IL-1R (TIR) signaling pathway, also referred to herein as the TLR signal transduction pathway. Changes in TLR8 activity can be measured by assays such as those disclosed herein, including expression of genes under control of κB-sensitive promoters and enhancers. Such naturally occurring genes include the genes encoding IL-1β, IL-6, IL-8, the p40 subunit of interleukin 12 (IL-12 p40), and the costimulatory molecules CD80 and CD86. Other genes can be placed under the control of such regulatory elements (see below) and thus serve to report the level of TLR8 signaling. Additional nucleotide sequence can be added to SEQ ID NO:29 or SEQ ID NO:33, preferably to the 5' or the 3' end of the open reading frame of SEQ ID NO:29, to yield a nucleotide sequence encoding a chimeric polypeptide that includes a detectable or reporter moiety, e.g., FLAG, luciferase (luc), green fluorescent protein (GFP), and others known by those skilled in the art.

SEQ ID NO:28 Human TLR8 amino acid (1041)

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MENMFLQSSM LTCIFLLISG SCELCAEENF SRSYPCDEKK QNDSVIAECS NRRLQEVPQT   60
VGKYVTELDL SDNFITHITN ESFQGLQNLT KINLNHNPNV QHQNGNPGIQ SNGLNITDGA  120
FLNLKNLREL LLEDNQLPQI PSGLPESLTE LSLIQNNIYN ITKEGISRLI NLKNLYLAWN  180
CYFNKVCEKT NIEDGVFETL TNLELLSLSF NSLSHVPPKL PSSLRKLFLS NTQIKYISEE  240
DFKGLINLTL LDLSGNCPRC FNAPFPCVPC DGGASINIDR FAFQNLTQLR YLNLSSTSLR  300
KINAAWFKNM PHLKVLDLEF NYLVGEIASG AFLTMLPRLE ILDLSFNYIK GSYPQHINIS  360
RNFSKLLSLR ALHLRGYVFQ ELREDDFQPL MQLPNLSTIN LGINFIKQID FKLFQNFSNL  420
EIIYLSENRI SPLVKDTRQS YANSSSFQRH IRKRRSTDFE FDPHSNFYHF TRPLIKPQCA  480
AYGKALDLSL NSIFFIGPNQ FENLPDIACL NLSANSNAQV LSGTEFSAIP HVKYLDLTNN  540
RLDFDNASAL TELSDLEVLD LSYNSHYFRI AGVTHHLEFI QNFTNLKVLN LSHNNIYTLT  600
DKYNLESKSL VELVFSGNRL DILWNDDDNR YISIFKGLKN LTRLDLSLNR LKHIPNEAFL  660
NLPASLTELH INDNMLKFFN WTLLQQFPRL ELLDLRGNKL LFLTDSLSDF TSSLRTLLLS  720
HNRISHLPSG FLSEVSSLKH LDLSSNLLKT INKSALETKT TTKLSMLELH GNPFECTCDI  780
GDFRRWMDEH LNVKIPRLVD VICASPGDQR GKSIVSLELT TCVSDVTAVI LFFFTFFITT  840
MVMLAALAHH LFYWDVWFIY NVCLAKVKGY RSLSTSQTFY DAYISYDTKD ASVTDWVINE  900
LRYHLEESRD KNVLLCLEER DWDPGLAIID NLMQSINQSK KTVFVLTKKY AKSWNFKTAF  960
YLALQRLMDE NMDVIIFILL EPVLQHSQYL RLRQRICKSS ILQWPDNPKA EGLFWQTLRN 1020
VVLTENDSRY NNMYVDSIKQ Y                                          1041
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SEQ ID NO:29 Human TLR8 nucleotide

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gttattgcag agtgcagcaa tcgtcgacta caggaagttc cccaaacggt gggcaaatat  240
gtgacagaac tagacctgtc tgataatttc atcacacaca taacgaatga atcatttcaa  300
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ggaaatcccg gtatacaatc aaatggcttg aatatcacag acggggcatt cctcaaccta  420
aaaaacctaa gggagttact gcttgaagac aaccagttac cccaaatacc ctctggtttg  480
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gatgatttcc agcccctgat gcagcttcca aacttatcga ctatcaactt gggtattaat 1260
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gaattttcag ccattcctca tgtcaaatat ttggatttga caaacaatag actagacttt 1680
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cccacagttt t                                                      3311
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SEQ ID NO:30 Human TLR8 amino acid (1059)

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DSVIAECSNR RLQEVPQTVG KYVTELDLSD NFITHITNES FQGLQNLTKI NLNHNPNVQH  120
QNGNPGIQSN GLNITDGAFL NLKNLRELLL EDNQLPQIPS GLPESLTELS LIQNNIYNIT  180
KEGISRLINL KNLYLAWNCY FNKVCEKTNI EDGVFETLTN LELLSLSFNS LSHVSPKLPS  240
SLRKLFLSNT QIKYISEEDF KGLINLTLLD LSGNCPRCFN APFPCVPCDG GASINIDRFA  300
FQNLTQLRYL NLSSTSLRKI NAAWFKNMPH LKVLDLEFNY LVGEIASGAF LTMLPRLEIL  360
DLSFNYIKGS YPQHINISRN FSKPLSLRAL HLRGYVFQEL REDDFQPLMQ LPNLSTINLG  420
INFIKQIDFK LFQNFSNLEI IYLSENRISP LVKDTRQSYA NSSSFQRHIR KRRSTDFEFD  480
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PHSNFYHFTR PLIKPQCAAY GKALDLSLNS IFFIGPNQFE NLPDIACLNL SANSNAQVLS  540
GTEFSAIPHV KYLDLTNNRL DFDNASALTE LSDLEVLDLS YNSHYFRIAG VTHHLEFIQN  600
FTNLKVLNLS HNNIYTLTDK YNLESKSLVE LVFSGNRLDI LWNDDDNRYI SIFKGLKNLT  660
RLDLSLNRLK HIPNEAFLNL PASLTELHIN DNMLKFFNWT LLQQFPRLEL LDLRGNKLLF  720
LTDSLSDFTS SLRTLLLSHN RISHLPSGFL SEVSSLKHLD LSSNLLKTIN KSALETKTTT  780
KLSMLELHGN PFECTCDIGD FRRWMDEHLN VKIPRLVDVI CASPGDQRGK SIVSLELTTC  840
VSDVTAVILF FFTFFITTMV MLAALAHHLF YWDVWFIYNV CLAKIKGYRS LSTSQTFYDA  900
YISYDTKDAS VTDWVINELR YHLEESRDKN VLLCLEERDW DPGLAIIDNL MQSINQSKKT  960
VFVLTKKYAK SWNFKTAFYL ALQRLMDENM DVIIFILLEP VLQHSQYLRL RQRICKSSIL 1020
QWPDNPKAEG LFWQTLRNVV LTENDSRYNN MYVDSIKQY                       1059
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SEQ ID NO:31 Human TLR8 nucleotide

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gagaccttga aggaagcctt tgaaagggag aatgaaggag tcatctttgc aaaatagctc  180
ctgcagcctg ggaaaggaga ctaaaaagga aacatgttc cttcagtcgt caatgctgac  240
ctgcattttc ctgctaatat ctggttcctg tgagttatgc gccgaagaaa atttttctag  300
aagctatcct tgtgatgaga aaaagcaaaa tgactcagtt attgcagagt gcagcaatcg  360
tcgactacag gaagttcccc aaacggtggg caaatatgtg acagaactag acctgtctga  420
taatttcatc acacacataa cgaatgaatc atttcaaggg ctgcaaaatc tcactaaaat  480
aaatctaaac cacaacccca atgtacagca ccagaacgga aatcccggta tacaatcaaa  540
tggcttgaat atcacagacg gggcattcct caacctaaaa aacctaaggg agttactgct  600
tgaagacaac cagttacccc aaataccctc tggtttgcca gagtctttga cagaacttag  660
tctaattcaa aacaatatat acaacataac taaagagggc atttcaagac ttataaactt  720
gaaaaatctc tatttggcct ggaactgcta ttttaacaaa gtttgcgaga aaactaacat  780
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tctttcacac gtgtcaccca aactgccaag ctccctacgc aaactttttc tgagcaacac  900
ccagatcaaa tacattagtg aagaagattt caagggattg ataaatttaa cattactaga  960
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ccacaacaac atttatactt taacagataa gtataacctg gaaagcaagt ccctggtaga 2040
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ataaaga                                                           3367
```

SEQ ID NO:32 Murine TLR8 amino acid

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IGKYVTNIDL SDNAITHITK ESFQKLQNLT KIDLNHNAKQ QHPNENKNGM NITEGALLSL  120
RNLTVLLLED NQLYTIPAGL PESLKELSLI QNNIFQVTKN NTFGLRNLER LYLGWNCYFK  180
CNQTFKVEDG AFKNLIHLKV LSLSFNNLFY VPPKLPSSLR KLFLSNAKIM NITQEDFKGL  240
ENLTLLDLSG NCPRCYNAPF PCTPCKENSS IHIHPLAFQS LTQLLYLNLS STSLRTIPST  300
WFENLSNLKE LHLEFNYLVQ EIASGAFLTK LPSLQILDLS FNFQYKEYLQ FINISSNFSK  360
LRSLKKLHLR GYVFRELKKK HFEHLQSLPN LATINLGINF IEKIDFKAFQ NFSKLDVIYL  420
SGNRIASVLD GTDYSSWRNR LRKPLSTDDD EFDPHVNFYH STKPLIKPQC TAYGKALDLS  480
LNNIFIIGKS QFEGFQDIAC LNLSFNANTQ VFNGTEFSSM PHIKYLDLTN NRLDFDDNNA  540
FSDLHDLEVL DLSHNAHYFS IAGVTHRLGF IQNLINLRVL NLSHNGIYTL TEESELKSIS  600
LKELVFSGNR LDHLWNANDG KYWSIFKSLQ NLIRLDLSYN NLQQIPNGAF LNLPQSLQEL  660
LISGNKLRFF NWTLLQYFPH LHLLDLSRNE LYFLPNCLSK FAHSLETLLL SHNHFSHLPS  720
GFLSEARNLV HLDLSFNTIK MINKSSLQTK MKTNLSILEL HGNYFDCTCD ISDFRSWLDE  780
NLNITIPKLV NVICSNPGDQ KSKSIMSLDL TTCVSDTTAA VLFFLTFLTT SMVMLAALVH  840
HLFYWDVWFI YHMCSAKLKG YRTSSTSQTF YDAYISYDTK DASVTDWVIN ELRYHLEESE  900
DKSVLLCLEE RDWDPGLPII DNLMQSINQS KKTIFVLTKK YAKSWNFKTA FYLALQRLMD  960
ENMDVIIFIL LEPVLQYSQY LRLRQRICKS SILQWPNNPK AENLFWQSLK NVVLTENDSR 1020
YDDLYIDSIR QY                                                     1032
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SEQ ID NO:33 Murine TLR8 nucleotide

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ggaaaacatg ccccctcagt catggattct gacgtgcttt tgtctgctgt cctctggaac  120
cagtgccatc ttccataaag cgaactattc cagaagctat ccttgtgacg agataaggca  180
caactccctt gtgattgcag aatgcaacca tcgtcaactg catgaagttc cccaaactat  240
aggcaagtat gtgacaaaca tagacttgtc agacaatgcc attacacata taacgaaaga  300
gtcctttcaa aagctgcaaa acctcactaa aatcgatctg aaccacaatg ccaaacaaca  360
gcacccaaat gaaaataaaa atggtatgaa tattacagaa ggggcacttc tcagcctaag  420
aaatctaaca gttttactgc tggaagacaa ccagttatat actatacctg ctgggttgcc  480
tgagtctttg aaagaactta gcctaattca aaacaatata tttcaggtaa ctaaaaacaa  540
cacttttggg cttaggaact tggaaagact ctatttgggc tggaactgct attttaaatg  600
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ctcattatct ttcaataacc ttttctatgt gccccccaaa ctaccaagtt ctctaaggaa  720
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cacccaactt ctctatctaa acctttccag cacttccctc aggacgattc cttctacctg  960
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agaaaacttg ttttggcaaa gtctgaaaaa tgtggtcttg actgaaaatg attcacggta 3120
tgacgatttg tacattgatt ccattaggca atactagtga tgggaagtca cgactctgcc 3180
atcataaaaa cacacagctt ctccttacaa tgaaccgaat                       3220
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Nucleotide and amino acid sequences of human and murine TLR9 are known. See, for example, GenBank Accession Nos. NM_017442, AF259262, AB045180, AF245704, AB045181, AF348140, AF314224, NM_031178; and NP_059138, AAF 72189, BAB19259, AAF78037, BAB19260, AAK29625, AAK28488, NP_112455. Human TLR9 is reported to exist in at least two isoforms, one 1032 amino acids long having a sequence provided in SEQ ID NO:34, and the other 1055 amino acids long having a sequence as provided in SEQ ID NO:36. Corresponding nucleotide sequences are provided as SEQ ID NO:35 and SEQ ID NO:37, respectively. The shorter of these two isoforms is believed to be more important. Murine TLR9 is 1032 amino acids long and has a sequence as provided in SEQ ID NO:38. A corresponding nucleotide sequence is provided as SEQ ID NO:39. TLR9 polypeptide includes an extracellular domain having leucine-rich repeat region, a transmembrane domain, and an intracellular domain that includes a TIR domain.

As used herein a "TLR9 polypeptide" refers to a polypeptide including a full-length TLR9 according to one of the sequences above, orthologs, allelic variants, SNPs, variants incorporating conservative amino acid substitutions, TLR9 fusion proteins, and functional

fragments of any of the foregoing. Preferred embodiments include human TLR9 polypeptides having at least 65 percent sequence identity, more preferably at least 80 percent sequence identity, even more preferably with at least 90 percent sequence identity, and most preferably with at least 95 percent sequence identity with the human TLR9 amino acid sequence of SEQ ID NO:34. Preferred embodiments also include murine TLR9 polypeptides having at least 65 percent sequence identity, more preferably at least 80 percent sequence identity, even more preferably with at least 90 percent sequence identity, and most preferably with at least 95 percent sequence identity with the murine TLR9 amino acid sequence of SEQ ID NO:38.

As used herein "TLR9 signaling" refers to an ability of a TLR9 polypeptide to activate the TLR/IL-1R (TIR) signaling pathway, also referred to herein as the TLR signal transduction pathway. Without meaning to be held to any particular theory, it is believed that the TLR/IL-1R signaling pathway involves signaling via the molecules myeloid differentiation marker 88 (MyD88) and tumor necrosis factor (TNF) receptor-associated factor 6 (TRAF6), leading to activation of kinases of the IκB kinase complex and the c-jun NH_2-terminal kinases (e.g., Jnk 1/2). Häcker H et al. (2000) *J Exp Med* 192:595-600. Changes in TLR9 activity can be measured by assays such as those disclosed herein, including expression of genes under control of κB-sensitive promoters and enhancers. Such naturally occurring genes include the genes encoding IL-1β, IL-6, IL-8, the p40 subunit of interleukin 12 (IL-12 p40), and the costimulatory molecules CD80 and CD86. Other genes can be placed under the control of such regulatory elements (see below) and thus serve to report the level of TLR9 signaling. Additional nucleotide sequence can be added to SEQ ID NO:35 or SEQ ID NO:39, preferably to the 5' or the 3' end of the open reading frame of SEQ ID NO:35, to yield a nucleotide sequence encoding a chimeric polypeptide that includes a detectable or reporter moiety, e.g., FLAG, luciferase (luc), green fluorescent protein (GFP), and others known by those skilled in the art.

SEQ ID NO:34 Human TLR9 amino acid (1032)

```
MGFCRSALHP LSLLVQAIML AMTLALGTLP AFLPCELQPH GLVNCNWLFL KSVPHFSMAA   60
PRGNVTSLSL SSNRIHHLHD SDFAHLPSLR HLNLKWNCPP VGLSPMHFPC HMTIEPSTFL  120
AVPTLEELNL SYNNIMTVPA LPKSLISLSL SHTNILMLDS ASLAGLHALR FLFMDGNCYY  180
KNPCRQALEV APGALLGLGN LTHLSLKYNN LTVVPRNLPS SLEYLLLSYN RIVKLAPEDL  240
ANLTALRVLD VGGNCRRCDH APNPCMECPR HFPQLHPDTF SHLSRLEGLV LKDSSLSWLN  300
ASWFRGLGNL RVLDLSENFL YKCITKTKAF QGLTQLRKLN LSFNYQKRVS FAHLSLAPSF  360
GSLVALKELD MHGIFFRSLD ETTLRPLARL PMLQTLRLQM NFINQAQLGI FRAFPGLRYV  420
DLSDNRISGA SELTATMGEA DGGEKVWLQP GDLAPAPVDT PSSEDFRPNC STLNFTLDLS  480
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RNNLVTVQPE MFAQLSHLQC LRLSHNCISQ AVNGSQFLPL TGLQVLDLSH NKLDLYHEHS  540
FTELPRLEAL DLSYNSQPFG MQGVGHNFSF VAHLRTLRHL SLAHNNIHSQ VSQQLCSTSL  600
RALDFSGNAL GHMWAEGDLY LHFFQGLSGL IWLDLSQNRL HTLLPQTLRN LPKSLQVLRL  660
RDNYLAFFKW WSLHFLPKLE VLDLAGNQLK ALTNGSLPAG TRLRRLDVSC NSISFVAPGF  720
FSKAKELREL NLSANALKTV DHSWFGPLAS ALQILDVSAN PLHCACGAAF MDFLLEVQAA  780
VPGLPSRVKC GSPGQLQGLS IFAQDLRLCL DEALSWDCFA LSLLAVALGL GVPMLHHLCG  840
WDLWYCFHLC LAWLPWRGRQ SGRDEDALPY DAFVVFDKTQ SAVADWVYNE LRGQLEECRG  900
RWALRLCLEE RDWLPGKTLF ENLWASVYGS RKTLFVLAHT DRVSGLLRAS FLLAQQRLLE  960
DRKDVVVLVI LSPDGRRSRY VRLRQRLCRQ SVLLWPHQPS GQRSFWAQLG MALTRDNHHF 1020
YNRNFCQGPT AE                                                    1032
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SEQ ID NO:35 Human TLR9 nucleotide

```
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cagcgccctg cacccgctgt ctctcctggt gcaggccatc atgctggcca tgaccctggc  180
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caactggctg ttcctgaagt ctgtgcccca cttctccatg gcagcacccc gtggcaatgt  300
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cctgcccagc ctgcggcatc tcaacctcaa gtggaactgc ccgccggttg gcctcagccc  420
catgcacttc ccctgccaca tgaccatcga gcccagcacc ttcttggctg tgcccaccct  480
ggaagagcta aacctgagct acaacaacat catgactgtg cctgcgctgc ccaaatccct  540
catatccctg tccctcagcc ataccaacat cctgatgcta gactctgcca gcctcgccgg  600
cctgcatgcc ctgcgcttcc tattcatgga cggcaactgt tattacaaga acccctgcag  660
gcaggcactg gaggtggccc cgggtgccct ccttggcctg ggcaacctca cccacctgtc  720
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gctgttgtcc tacaaccgca tcgtcaaact ggcgcctgag gacctggcca atctgaccgc  840
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actcacctca cctctgc                                               3258
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SEQ ID NO:36 Human TLR9 amino acid (1055)

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QPHGLVNCNW LFLKSVPHFS MAAPRGNVTS LSLSSNRIHH LHDSDFAHLP SLRHLNLKWN  120
CPPVGLSPMH FPCHMTIEPS TFLAVPTLEE LNLSYNNIMT VPALPKSLIS LSLSHTNILM  180
LDSASLAGLH ALRFLFMDGN CYYKNPCRQA LEVAPGALLG LGNLTHLSLK YNNLTVVPRN  240
LPSSLEYLLL SYNRIVKLAP EDLANLTALR VLDVGGNCRR CDHAPNPCME CPRHFPQLHP  300
DTFSHLSRLE GLVLKDSSLS WLNASWFRGL GNLRVLDLSE NFLYKCITKT KAFQGLTQLR  360
KLNLSFNYQK RVSFAHLSLA PSFGSLVALK ELDMHGIFFR SLDETTLRPL ARLPMLQTLR  420
LQMNFINQAQ LGIFRAFPGL RYVDLSDNRI SGASELTATM GEADGGEKVW LQPGDLAPAP  480
VDTPSSEDFR PNCSTLNFTL DLSRNNLVTV QPEMFAQLSH LQCLRLSHNC ISQAVNGSQF  540
LPLTGLQVLD LSHNKLDLYH EHSFTELPRL EALDLSYNSQ PFGMQGVGHN FSFVAHLRTL  600
RHLSLAHNNI HSQVSQQLCS TSLRALDFSG NALGHMWAEG DLYLHFFQGL SGLIWLDLSQ  660
NRLHTLLPQT LRNLPKSLQV LRLRDNYLAF FKWWSLHFLP KLEVLDLAGN QLKALTNGSL  720
PAGTRLRRLD VSCNSISFVA PGFFSKAKEL RELNLSANAL KTVDHSWFGP LASALQILDV  780
SANPLHCACG AAFMDFLLEV QAAVPGLPSR VKCGSPGQLQ GLSIFAQDLR LCLDEALSWD  840
CFALSLLAVA LGLGVPMLHH LCGWDLWYCF HLCLAWLPWR GRQSGRDEDA LPYDAFVVFD  900
KTQSAVADWV YNELRGQLEE CRGRWALRLC LEERDWLPGK TLFENLWASV YGSRKTLFVL  960
AHTDRVSGLL RASFLLAQQR LLEDRKDVVV LVILSPDGRR SRYVRLRQRL CRQSVLLWPH 1020
QPSGQRSFWA QLGMALTRDN HHFYNRNFCQ GPTAE                           1055
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SEQ ID NO:37 Human TLR9 nucleotide

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cagccccacg gcctggtgaa ctgcaactgg ctgttcctga agtctgtgcc ccacttctcc  240
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gagcactcat tcacggagct accacgactg gaggccctgg acctcagcta caacagccag 1720
ccctttggca tgcagggcgt gggccacaac ttcagcttcg tggctcacct gcgcaccctg 1800
cgccacctca gcctggccca caacaacatc cacagccaag tgtcccagca gctctgcagt 1860
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cagcccagtg gtcagcgcag cttctgggcc cagctgggca tggccctgac cagggacaac 3120
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SEQ ID NO:38 Murine TLR9 amino acid

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AMRTLEELNL SYNGITTVPR LPSSLVNLSL SHTNILVLDA NSLAGLYSLR VLFMDGNCYY  180
KNPCTGAVKV TPGALLGLSN LTHLSLKYNN LTKVPRQLPP SLEYLLVSYN LIVKLGPEDL  240
ANLTSLRVLD VGGNCRRCDH APNPCIECGQ KSLHLHPETF HHLSHLEGLV LKDSSLHTLN  300
SSWFQGLVNL SVLDLSENFL YESINHTNAF QNLTRLRKLN LSFNYRKKVS FARLHLASSF  360
KNLVSLQELN MNGIFFRSLN KYTLRWLADL PKLHTLHLQM NFINQAQLSI FGTFRALRFV  420
DLSDNRISGP STLSEATPEE ADDAEQEELL SADPHPAPLS TPASKNFMDR CKNFKFTMDL  480
SRNNLVTIKP EMFVNLSRLQ CLSLSHNSIA QAVNGSQFLP LTNLQVLDLS HNKLDLYHWK  540
SFSELPQLQA LDLSYNSQPF SMKGIGHNFS FVAHLSMLHS LSLAHNDIHT RVSSHLNSNS  600
VRFLDFSGNG MGRMWDEGGL YLHFFQGLSG LLKLDLSQNN LHILRPQNLD NLPKSLKLLS  660
LRDNYLSFFN WTSLSFLPNL EVLDLAGNQL KALTNGTLPN GTLLQKLDVS SNSIVSVVPA  720
FFALAVELKE VNLSHNILKT VDRSWFGPIV MNLTVLDVRS NPLHCACGAA FVDLLLEVQT  780
KVPGLANGVK CGSPGQLQGR SIFAQDLRLC LDEVLSWDCF GLSLLAVAVG MVVPILHHLC  840
GWDVWYCFHL CLAWLPLLAR SRRSAQALPY DAFVVFDKAQ SAVADWVYNE LRVRLEERRG  900
RRALRLCLED RDWLPGQTLF ENLWASIYGS RKTLFVLAHT DRVSGLLRTS FLLAQQRLLE  960
DRKDVVVLVI LRPDAHRSRY VRLRQRLCRQ SVLFWPQQPN GQGGFWAQLS TALTRDNRHF 1020
YNQNFCRGPT AE                                                    1032
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SEQ ID NO:39 Murine TLR9 nucleotide

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tcccgagttg ctctgcctgc                                             3200
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Ribonucleoside vanadyl complexes (i.e., mixtures of adenine, cytosine, guanosine, and uracil ribonucleoside vanadyl complexes), are well known by those of skill in the art as RNAse inhibitors. Berger SL et al. (1979) *Biochemistry* 18:5143; Puskas RS et al. (1982) *Biochemistry* 21:4602. Ribonucleoside vanadyl complexes are commercially available from suppliers including Sigma-Aldrich, Inc.

In one embodiment, the immunostimulatory G,U-containing RNA oligomer of the invention does not contain a CpG dinucleotide and is not a CpG immunostimulatory nucleic acid. In some embodiments, a CpG immunostimulatory nucleic acid is used in the methods of the invention.

A CpG immunostimulatory nucleic acid is a nucleic acid which contains a CG dinucleotide, the C residue of which is unmethylated. CpG immunostimulatory nucleic acids are known to stimulate Th1-type immune responses. CpG sequences, while relatively rare in human DNA are commonly found in the DNA of infectious organisms such as bacteria. The human immune system has apparently evolved to recognize CpG sequences as an early warning sign of infection and to initiate an immediate and powerful immune response against invading pathogens without causing adverse reactions frequently seen with other immune stimulatory agents. Thus CpG containing nucleic acids, relying on this innate immune defense mechanism can utilize a unique and natural pathway for immune therapy. The effects of CpG nucleic acids on immune modulation have been described extensively in U.S. patents such as US 6,194,388 B1, US 6,207,646 B1, US 6,239,116 B1 and US 6,218,371 B1, and published patent applications, such as PCT/US98/03678, PCT/US98/10408, PCT/US98/04703, and PCT/US99/09863. The entire contents of each of these patents and patent applications is hereby incorporated by reference.

A CpG nucleic acid is a nucleic acid which includes at least one unmethylated CpG dinucleotide. A nucleic acid containing at least one unmethylated CpG dinucleotide is a nucleic acid molecule which contains an unmethylated cytosine in a cytosine-guanine dinucleotide sequence (i.e., "CpG DNA" or DNA containing a 5' cytosine followed by 3' guanosine and linked by a phosphate bond) and activates the immune system. The CpG nucleic acids can be double-stranded or single-stranded. Generally, double-stranded molecules are more stable *in vivo*, while single-stranded molecules have increased immune activity. Thus in some aspects of the invention it is preferred that the nucleic acid be single stranded and in other aspects it is preferred that the nucleic acid be double stranded. In certain embodiments, while the nucleic acid is single stranded, it is capable of forming secondary and tertiary structures (e.g., by folding back on itself, or by hybridizing with itself either throughout its entirety or at select segments along its length). Accordingly, while the primary structure of such a nucleic acid may be single stranded, its higher order structures may be double or triple stranded. The terms CpG nucleic acid or CpG oligonucleotide as

used herein refer to an immunostimulatory CpG nucleic acid unless otherwise indicated. The entire immunostimulatory nucleic acid can be unmethylated or portions may be unmethylated but at least the C of the 5' CG 3' must be unmethylated.

In one aspect the invention provides a method of activating an immune cell. The method involves contacting an immune cell with an immunostimulatory composition of the invention, described above, in an effective amount to induce activation of the immune cell. As used herein, an "immune cell" is cell that belongs to the immune system. Immune cells participate in the regulation and execution of inflammatory and immune responses. They include, without limitation, B lymphocytes (B cells), T lymphocytes (T cells), natural killer (NK) cells, dendritic cells, other tissue-specific antigen-presenting cells (e.g., Langerhans cells), macrophages, monocytes, granulocytes (neutrophils, eosinophils, basophils), and mast cells. Splenocytes, thymocytes, and peripheral blood mononuclear cells (PBMCs) include immune cells. Immune cells can be isolated from the blood, spleen, marrow, lymph nodes, thymus, and other tissues using methods well known to those of skill in the art. Immune cells can also include certain cell lines as well as primary cultures maintained in vitro or ex vivo.

In one embodiment the activation of the immune cell involves secretion of a cytokine by the immune cell. In one embodiment the activation of the immune cell involves secretion of a chemokine by the immune cell. In one embodiment the activation of the immune cell involves expression of a costimulatory/accessory molecule by the immune cell. In one embodiment the costimulatory/accessory molecule is selected from the group consisting of intercellular adhesion molecules (ICAMs, e.g., CD54), leukocyte function-associated antigens (LFAs, e.g., CD58), B7s (CD80, CD86), and CD40.

"Activation of an immune cell" shall refer to a transition of an immune cell from a resting or quiescent state to a state of heightened metabolic activity and phenotype associated with immune cell function. Such immune cell function can include, for example, secretion of soluble products such as immunoglobulins, cytokines, and chemokines; cell surface expression of costimulatory/accessory molecules and MHC antigens; immune cell migration; phagocytosis and cytotoxic activity toward target cells; and immune cell maturation. In some instances immune activation can refer to Th1 immune activation; in other instances immune activation can refer to Th2 immune activation.

"Th1 immune activation" as used herein refers to the activation of immune cells to express Th1-like secreted products, including certain cytokines, chemokines, and subclasses

of immunoglobulin; and activation of certain immune cells. Th1-like secreted products include, for example, the cytokines IFN-γ, IL-2, IL-12, IL-18, TNF-α, and the chemokine IP-10 (CXCL10). In the mouse, Th1 immune activation stimulates secretion of IgG2a. Th1 immune activation also may include activation of NK cells and dendritic cells, i.e., cells involved in cellular immunity. Th1 immune activation is believed to counter-regulate Th2 immune activation.

"Th2 immune activation" as used herein refers to the activation of immune cells to express Th2-like secreted products, including certain cytokines and subclasses of immunoglobulin. Th2-like secreted products include, for example, the cytokines IL-4 and IL-10. In the mouse, Th2 immune activation stimulates secretion of IgG1 and IgE. Th2 immune activation is believed to counter-regulate Th1 immune activation.

In another aspect, the invention provides a method of inducing an immune response in a subject. The method entails administering to a subject a composition of the invention in an effective amount to induce an immune response in the subject. Thus the compositions of the invention may be used to treat a subject in need of immune activation. A subject in need of immune activation may include a subject in need of Th1-like immune activation.

The compositions and methods of the invention can be used, alone or in conjunction with other agents, to treat a subject in need of Th1-like immune activation. A "subject in need of Th1-like immune activation" is a subject that has or is at risk of developing a disease, disorder, or condition that would benefit from an immune response skewed toward Th1. Such a subject may have or be at risk of having a Th2-mediated disorder that is susceptible to Th1-mediated cross-regulation or suppression. Such disorders include, for example, certain organ-specific autoimmune diseases. Alternatively, such a subject may have or be at risk of having a Th1-deficient state. Such disorders include, for example, tumors, infections with intracellular pathogens, and AIDS.

As used herein, "G,U-rich RNA" shall mean RNA at least 5 nucleotides long that by base composition is at least 60 percent, more preferably at least 80 percent, and most preferably at least 90 percent guanine (G) and uracil (U). Such base composition is measured over the full length of the RNA if it is no more than 10 bases long, and over a stretch of at least 10 contiguous bases if the RNA is more than 10 bases long.

As used herein, "G-rich RNA" shall mean RNA that by base composition is at least 70 percent, more preferably at least 80 percent, even more preferably at least 90 percent, and

most preferably at least 95 percent guanine (G). Such base composition is measured over the full length of the RNA if it is no more than 10 bases long, and over a stretch of at least 10 contiguous bases if the RNA is more than 10 bases long.

In some embodiments the compositions of the present invention include a DNA:RNA conjugate. A DNA:RNA conjugate shall mean a molecule or complex that includes at least one deoxyribonucleoside linked to at least one ribonucleoside. The deoxyribonucleoside and ribonucleoside components may be linked by base pair interaction. Alternatively, the deoxyribonucleoside and ribonucleoside components may be linked by covalent linkage between the sugar moieties of the at least one deoxyribonucleoside and the at least one ribonucleoside. The covalent linkage between the sugar moieties may be direct or indirect, for example through a linker. Base pair interactions typically are, but are not limited to, non-covalent Watson-Crick type base pair interactions. Other base pair interactions, including non-covalent (e.g., Hoogstein base pairing) and covalent interactions are contemplated by the invention. Base pair interactions also typically will involve duplex formation involving two strands, but higher order interactions are also contemplated by the invention.

A DNA:RNA conjugate involving a covalent linkage between the sugar moieties of the at least one deoxyribonucleoside and the at least one ribonucleoside is referred to herein as having a chimeric DNA:RNA backbone. The DNA:RNA conjugate having a chimeric DNA:RNA backbone will have primary structure defined by its base sequence, and it may further have a secondary or higher order structure. A secondary or higher order structure will include at least one intramolecular base pair interaction, e.g., a stem-loop structure, or intermolecular base pair interaction.

Heteroduplex base pairing shall refer to intramolecular or intermolecular base pair interaction between DNA and RNA. For example, heteroduplex base pairing may occur between individual complementary single-stranded DNA and RNA molecules. Alternatively, as in the case of suitable DNA:RNA chimeric backbone nucleic acid molecules, heteroduplex base pairing may occur between complementary DNA and RNA regions within the same molecule.

In some embodiments the compositions of the present invention include a chimeric DNA:RNA backbone having a cleavage site between the DNA and RNA. A cleavage site refers to a structural element along the chimeric backbone that is susceptible to cleavage by any suitable means. The cleavage site may be a phosphodiester bond that is relatively

susceptible to cleavage by endonuclease. In this instance the DNA and RNA each may include internucleotide linkages that are stabilized, such that the chimeric backbone is most susceptible to endonuclease cleavage at the phosphodiester junction between the stabilized DNA and the stabilized RNA. The cleavage site may be designed so that it is susceptible to cleavage under certain pH conditions, e.g., relatively more stable at higher pH than at lower pH, or vice versa. Such pH sensitivity may be accomplished, for example, by preparation of the chimeric DNA:RNA composition in liposomes. The cleavage site may involve a disulfide linkage. Such disulfide linkage may be relatively more stable under oxidizing conditions than under reducing conditions, e.g., the latter conditions present within an endosome. The cleavage site may also involve a linker that is susceptible to cleavage by an enzyme, pH, redox condition, or the like. In some embodiments the composition may include more than one cleavage site.

Conjugates of the invention permit selection of fixed molar ratios of the components of the conjugates. In the case of DNA:RNA conjugates it may be advantageous or convenient to have a 1:1 ratio of DNA and RNA. Conjugates that are heteroduplex DNA:RNA will commonly have a 1:1 ratio of DNA and RNA. Conjugates that have a chimeric DNA:RNA backbone may also commonly have a 1:1 ratio of DNA and RNA. Conjugates having other DNA:RNA ratios are contemplated by the invention, including, but not limited to, 1:2, 1:3, 1:4, 2:1, 3:1, 4:1, and so on. The conjugation may stabilize one or more components in comparison to the stability of the same component or components alone. Conjugatation may also facilitate delivery of the components into cells at the selected ratio.

Cleavage sites may serve any of several purposes useful in the present invention. Once delivered to a cell of interest, the components joined via the cleavage site (or sites) may be liberated to become independently or optimally active within the cell or in the vicinity of the cell. In some embodiments the cleavage sites may be important to pharmacokinetics of at least one of the components of the conjugate. For instance, the cleavage sites may be designed and selected to confer an extended time release of one of the components.

The invention generally provides efficient methods of identifying immunostimulatory compounds and the compounds and agents so identified. Generally, the screening methods involve assaying for compounds which inhibit or enhance signaling through a particular TLR. The methods employ a TLR, a suitable reference ligand for the TLR, and a candidate immunostimulatory compound. The selected TLR is contacted with a suitable refernce

compound (TLR ligand) and a TLR-mediated reference signal is measured. The selected TLR is also contacted with a candidate immunostimulatory compound and a TLR-mediated test signal is measured. The test signal and the reference signal are then compared. A favorable candidate immunostimulatory compound may subsequently be used as a reference compound in the assay. Such methods are adaptable to automated, high throughput screening of candidate compounds. Examples of such high throughput screening methods are described in U.S. Pat. Nos. 6,103,479; 6,051,380; 6,051,373; 5,998,152; 5,876,946; 5,708,158; 5,443,791; 5,429,921; and 5,143,854.

The assay mixture comprises a candidate immunostimulatory compound. Typically, a plurality of assay mixtures are run in parallel with different agent concentrations to obtain a different response to the various concentrations. Typically, one of these concentrations serves as a negative control, i.e., at zero concentration of agent or at a concentration of agent below the limits of assay detection. Candidate immunostimulatory compounds encompass numerous chemical classes, although typically they are organic compounds. Preferably, the candidate immunostimulatory compounds are small organic compounds, i.e., those having a molecular weight of more than 50 yet less than about 2500. Polymeric candidate immunostimulatory compounds can have higher molecular weights, e.g., oligonucleotides in the range of about 2500 to about 12,500. Candidate immunostimulatory compounds comprise functional chemical groups necessary for structural interactions with polypeptides, and may include at least an amine, carbonyl, hydroxyl or carboxyl group, preferably at least two of the functional chemical groups and more preferably at least three of the functional chemical groups. The candidate immunostimulatory compounds can comprise cyclic carbon or heterocyclic structure and/or aromatic or polyaromatic structures substituted with one or more of the above-identified functional groups. Candidate immunostimulatory compounds also can be biomolecules such as nucleic acids, peptides, saccharides, fatty acids, sterols, isoprenoids, purines, pyrimidines, derivatives or structural analogs of the above, or combinations thereof and the like. Where the candidate immunostimulatory compound is a nucleic acid, the candidate immunostimulatory compound typically is a DNA or RNA molecule, although modified nucleic acids having non-natural bonds or subunits are also contemplated.

Candidate immunostimulatory compounds are obtained from a wide variety of sources, including libraries of natural, synthetic, or semisynthetic compounds, or any

combination thereof. For example, numerous means are available for random and directed synthesis of a wide variety of organic compounds and biomolecules, including expression of randomized oligonucleotides, synthetic organic combinatorial libraries, phage display libraries of random peptides, and the like. Alternatively, libraries of natural compounds in the form of bacterial, fungal, plant and animal extracts are available or readily produced. Additionally, natural and synthetically produced libraries and compounds can be readily modified through conventional chemical, physical, and biochemical means. Further, known pharmacological agents may be subjected to directed or random chemical modifications such as acylation, alkylation, esterification, amidification, etc., to produce structural analogs of the candidate immunostimulatory compounds.

Therefore, a source of candidate immunostimulatory compounds are libraries of molecules based on known TLR ligands, e.g., CpG oligonucleotides known to interact with TLR9, in which the structure of the ligand is changed at one or more positions of the molecule to contain more or fewer chemical moieties or different chemical moieties. The structural changes made to the molecules in creating the libraries of analog inhibitors can be directed, random, or a combination of both directed and random substitutions and/or additions. One of ordinary skill in the art in the preparation of combinatorial libraries can readily prepare such libraries based on existing TLR9 ligands.

A variety of other reagents also can be included in the mixture. These include reagents such as salts, buffers, neutral proteins (e.g., albumin), detergents, etc. which may be used to facilitate optimal protein-protein and/or protein-nucleic acid binding. Such a reagent may also reduce non-specific or background interactions of the reaction components. Other reagents that improve the efficiency of the assay such as protease inhibitors, nuclease inhibitors, antimicrobial agents, and the like may also be used.

The order of addition of components, incubation temperature, time of incubation, and other parameters of the assay may be readily determined. Such experimentation merely involves optimization of the assay parameters, not the fundamental composition of the assay. Incubation temperatures typically are between 4°C and 40°C. Incubation times preferably are minimized to facilitate rapid, high throughput screening, and typically are between 1 minute and 10 hours.

After incubation, the level of TLR signaling is detected by any convenient method available to the user. For cell-free binding type assays, a separation step is often used to

separate bound from unbound components. The separation step may be accomplished in a variety of ways. For example, separation can be accomplished in solution, or, conveniently, at least one of the components is immobilized on a solid substrate, from which the unbound components may be easily separated. The solid substrate can be made of a wide variety of materials and in a wide variety of shapes, e.g., microtiter plate, microbead, dipstick, resin particle, etc. The substrate preferably is chosen to maximize signal-to-noise ratios, primarily to minimize background binding, as well as for ease of separation and cost.

Separation may be effected for example, by removing a bead or dipstick from a reservoir, emptying or diluting a reservoir such as a microtiter plate well, rinsing a bead, particle, chromatographic column or filter with a wash solution or solvent. The separation step preferably includes multiple rinses or washes. For example, when the solid substrate is a microtiter plate, the wells may be washed several times with a washing solution, which typically includes those components of the incubation mixture that do not participate in specific bindings such as salts, buffer, detergent, non-specific protein, etc. Where the solid substrate is a magnetic bead, the beads may be washed one or more times with a washing solution and isolated using a magnet.

Detection may be effected in any convenient way for cell-based assays such as measurement of an induced polypeptide within, on the surface of, or secreted by the cell. Examples of detection methods useful in cell-based assays include fluorescence-activated cell sorting (FACS) analysis, bioluminescence, fluorescence, enzyme-linked immunosorbent assay (ELISA), reverse transcriptase-polymerase chain reaction (RT-PCR), and the like. Examples of detection methods useful in cell-free assays include bioluminescence, fluorescence, enzyme-linked immunosorbent assay (ELISA), reverse transcriptase-polymerase chain reaction (RT-PCR), and the like.

A subject shall mean a human or animal including but not limited to a dog, cat, horse, cow, pig, sheep, goat, chicken, rodent, e.g., rats and mice, primate, e.g., monkey, and fish or aquaculture species such as fin fish (e.g., salmon) and shellfish (e.g., shrimp and scallops). Subjects suitable for therapeutic or prophylactic methods include vertebrate and invertebrate species. Subjects can be house pets (e.g., dogs, cats, fish, etc.), agricultural stock animals (e.g., cows, horses, pigs, chickens, etc.), laboratory animals (e.g., mice, rats, rabbits, etc.), zoo animals (e.g., lions, giraffes, etc.), but are not so limited. Although many of the embodiments

described herein relate to human disorders, the invention is also useful for treating other nonhuman vertebrates.

As used herein, the term "treat", when used with respect to one of the disorders described herein, refers both to a prophylactic treatment which decreases the likelihood that a subject will develop the disorder as well as to treatment of an established disorder, e.g., to reduce or eliminate the disorder or symptoms of the disorder, or to prevent the disorder or symptoms of the disorder from becoming worse.

A subject that has a disorder refers to a subject that has an objectively measureable manifestation of the disorder. Thus for example a subject that has a cancer is a subject that has detectable cancerous cells. A subject that has an infection is a subject that has been exposed to an infectious organism and has acute or chronic detectable levels of the organism in the body. The infection may be latent (dormant) or active.

A subject at risk of having a disorder is defined as a subject that has a higher than normal risk of developing the disorder. The normal risk is generally the risk of a population of normal individuals that do not have the disorder and that are not identifiably predisposed, e.g., either genetically or environmentally, to developing the disorder. Thus a subject at risk of having a disorder may include, without limitation, a subject that is genetically predisposed to developing the disorder, as well as a subject that is or will be exposed to an environmental agent known or believed to cause the disorder. Environmental agents specifically include, but are not limited to, infectious agents such as viruses, bacteria, fungi, and parasites. Other environmental agents may include, for example, tobacco smoke, certain organic chemicals, asbestos, and the like.

The term "effective amount" of a nucleic acid or other therapeutic agent refers to the amount necessary or sufficient to realize a desired biologic effect. In general, an effective amount is that amount necessary to cause activation of the immune system, resulting potentially in the development of an antigen-specific immune response. In some embodiments, the nucleic acid or other therapeutic agent are administered in an effective amount to stimulate or induce a Th1 immune response or a general immune response. An effective amount to stimulate a Th1 immune response may be defined as that amount which stimulates the production of one or more Th1-type cytokines, such as IL-2, IL-12, TNF-α, and IFN-γ, and/or production of one or more Th1-type antibodies.

In yet another aspect the invention provides a method of inducing an immune response in a subject. The method according to this aspect of the invention involves administering to a subject an antigen, and administering to the subject an immunostimulatory composition of the invention in an effective amount to induce an immune response to the antigen. It is to be noted that the antigen may be administered before, after, or concurrently with the immunostimulatory composition of the invention. In addition, both the antigen and the immunostimulatory compound can be administered to the subject more than once.

The invention further provides, in yet another aspect, a method of inducing an immune response in a subject. The method according to this aspect of the invention involves isolating dendritic cells of a subject, contacting the dendritic cells ex vivo with an immunostimulatory composition of the invention, contacting the dendritic cells ex vivo with an antigen, and administering the contacted dendritic cells to the subject.

The term "antigen" refers to a molecule capable of provoking an immune response. The term antigen broadly includes any type of molecule that is recognized by a host system as being foreign. Antigens include but are not limited to microbial antigens, cancer antigens, and allergens. Antigens include, but are not limited to, cells, cell extracts, proteins, polypeptides, peptides, polysaccharides, polysaccharide conjugates, peptide and non-peptide mimics of polysaccharides and other molecules, small molecules, lipids, glycolipids, and carbohydrates. Many antigens are protein or polypeptide in nature, as proteins and polypeptides are generally more antigenic than carbohydrates or fats.

The antigen may be an antigen that is encoded by a nucleic acid vector or it may not be encoded in a nucleic acid vector. In the former case the nucleic acid vector is administered to the subject and the antigen is expressed *in vivo*. In the latter case the antigen may be administered directly to the subject. An antigen not encoded in a nucleic acid vector as used herein refers to any type of antigen that is not a nucleic acid. For instance, in some aspects of the invention the antigen not encoded in a nucleic acid vector is a peptide or a polypeptide. Minor modifications of the primary amino acid sequences of peptide or polypeptide antigens may also result in a polypeptide which has substantially equivalent antigenic activity as compared to the unmodified counterpart polypeptide. Such modifications may be deliberate, as by site-directed mutagenesis, or may be spontaneous. All of the polypeptides produced by these modifications are included herein as long as antigenicity still exists. The peptide or polypeptide may be, for example, virally derived.

The antigens useful in the invention may be any length, ranging from small peptide fragments of a full length protein or polypeptide to the full length form. For example, the antigen may be less than 5, less than 8, less than 10, less than 15, less than 20, less than 30, less than 50, less than 70, less than 100, or more amino acid residues in length, provided it stimulates a specific immune response.

The nucleic acid encoding the antigen is operatively linked to a gene expression sequence which directs the expression of the antigen nucleic acid within a eukaryotic cell. The gene expression sequence is any regulatory nucleotide sequence, such as a promoter sequence or promoter-enhancer combination, which facilitates the efficient transcription and translation of the antigen nucleic acid to which it is operatively linked. The gene expression sequence may, for example, be a mammalian or viral promoter, such as a constitutive or inducible promoter. Constitutive mammalian promoters include, but are not limited to, the promoters for the following genes: hypoxanthine phosphoribosyl transferase (HPRT), adenosine deaminase, pyruvate kinase, β-actin promoter and other constitutive promoters. Exemplary viral promoters which function constitutively in eukaryotic cells include, for example, promoters from the cytomegalovirus (CMV), simian virus (e.g., SV40), papilloma virus, adenovirus, human immunodeficiency virus (HIV), Rous sarcoma virus, the long terminal repeats (LTR) of Moloney leukemia virus and other retroviruses, and the thymidine kinase promoter of herpes simplex virus. Other constitutive promoters are known to those of ordinary skill in the art. The promoters useful as gene expression sequences of the invention also include inducible promoters. Inducible promoters are expressed in the presence of an inducing agent. For example, the metallothionein promoter is induced to promote transcription and translation in the presence of certain metal ions. Other inducible promoters are known to those of ordinary skill in the art.

In general, the gene expression sequence shall include, as necessary, 5' non-transcribing and 5' non-translating sequences involved with the initiation of transcription and translation, respectively, such as a TATA box, capping sequence, CAAT sequence, and the like. Especially, such 5' non-transcribing sequences will include a promoter region which includes a promoter sequence for transcriptional control of the operably joined antigen nucleic acid. The gene expression sequences optionally include enhancer sequences or upstream activator sequences as desired.

The antigen nucleic acid is operatively linked to the gene expression sequence. As used herein, the antigen nucleic acid sequence and the gene expression sequence are said to be operably linked when they are covalently linked in such a way as to place the expression or transcription and/or translation of the antigen coding sequence under the influence or control of the gene expression sequence. Two DNA sequences are said to be operably linked if induction of a promoter in the 5' gene expression sequence results in the transcription of the antigen sequence and if the nature of the linkage between the two DNA sequences does not (1) result in the introduction of a frame-shift mutation, (2) interfere with the ability of the promoter region to direct the transcription of the antigen sequence, or (3) interfere with the ability of the corresponding RNA transcript to be translated into a protein. Thus, a gene expression sequence would be operably linked to an antigen nucleic acid sequence if the gene expression sequence were capable of effecting transcription of that antigen nucleic acid sequence such that the resulting transcript is translated into the desired protein or polypeptide.

The antigen nucleic acid of the invention may be delivered to the immune system alone or in association with a vector. In its broadest sense, a vector is any vehicle capable of facilitating the transfer of the antigen nucleic acid to the cells of the immune system so that the antigen can be expressed and presented on the surface of the immune cell. The vector generally transports the nucleic acid to the immune cells with reduced degradation relative to the extent of degradation that would result in the absence of the vector. The vector optionally includes the above-described gene expression sequence to enhance expression of the antigen nucleic acid in immune cells. In general, the vectors useful in the invention include, but are not limited to, plasmids, phagemids, viruses, other vehicles derived from viral or bacterial sources that have been manipulated by the insertion or incorporation of the antigen nucleic acid sequences. Viral vectors are a preferred type of vector and include, but are not limited to, nucleic acid sequences from the following viruses: retrovirus, such as Moloney murine leukemia virus, Harvey murine sarcoma virus, murine mammary tumor virus, and Rous sarcoma virus; adenovirus, adeno-associated virus; SV40-type viruses; polyoma viruses; Epstein-Barr viruses; papilloma viruses; herpes virus; vaccinia virus; polio virus; and RNA virus such as a retrovirus. One can readily employ other vectors not named but known in the art.

Preferred viral vectors are based on non-cytopathic eukaryotic viruses in which non-essential genes have been replaced with the gene of interest. Non-cytopathic viruses

include retroviruses, the life cycle of which involves reverse transcription of genomic viral RNA into DNA with subsequent proviral integration into host cellular DNA. Retroviruses have been approved for human gene therapy trials. Most useful are those retroviruses that are replication-deficient (i.e., capable of directing synthesis of the desired proteins, but incapable of manufacturing an infectious particle). Such genetically altered retroviral expression vectors have general utility for the high-efficiency transduction of genes *in vivo*. Standard protocols for producing replication-deficient retroviruses (including the steps of incorporation of exogenous genetic material into a plasmid, transfection of a packaging cell lined with plasmid, production of recombinant retroviruses by the packaging cell line, collection of viral particles from tissue culture media, and infection of the target cells with viral particles) are provided in Kriegler, M., Gene Transfer and Expression, A Laboratory Manual, W.H. Freeman Co., New York (1990) and Murray, E.J. Methods in Molecular Biology, vol. 7, Humana Press, Inc., Cliffton, New Jersey (1991).

A preferred virus for certain applications is the adeno-associated virus, a double-stranded DNA virus. The adeno-associated virus can be engineered to be replication-deficient and is capable of infecting a wide range of cell types and species. It further has advantages, such as heat and lipid solvent stability; high transduction frequencies in cells of diverse lineages, including hemopoietic cells; and lack of superinfection inhibition thus allowing multiple series of transductions. Reportedly, wild-type adeno-associated virus manifest some preference for integration sites into human cellular DNA, thereby minimizing the possibility of insertional mutagenesis and variability of inserted gene expression characteristic of retroviral infection. In addition, wild-type adeno-associated virus infections have been followed in tissue culture for greater than 100 passages in the absence of selective pressure, implying that the adeno-associated virus genomic integration is a relatively stable event. The adeno-associated virus can also function in an extrachromosomal fashion. Recombinant adeno-associated viruses that lack the replicase protein apparently lack this integration sequence specificity.

Other vectors include plasmid vectors. Plasmid vectors have been extensively described in the art and are well-known to those of skill in the art. See, e.g., Sambrook et al., Molecular Cloning: A Laboratory Manual, Second Edition, Cold Spring Harbor Laboratory Press, 1989. In the last few years, plasmid vectors have been found to be particularly advantageous for delivering genes to cells *in vivo* because of their inability to replicate within

and integrate into a host genome. These plasmids, however, having a promoter compatible with the host cell, can express a peptide from a gene operatively encoded within the plasmid. Some commonly used plasmids include pBR322, pUC18, pUC19, pRc/CMV, SV40, and pBlueScript. Other plasmids are well-known to those of ordinary skill in the art. Additionally, plasmids may be custom designed using restriction enzymes and ligation reactions to remove and add specific fragments of DNA.

It has recently been discovered that gene-carrying plasmids can be delivered to the immune system using bacteria. Modified forms of bacteria such as *Salmonella* can be transfected with the plasmid and used as delivery vehicles. The bacterial delivery vehicles can be administered to a host subject orally or by other administration means. The bacteria deliver the plasmid to immune cells, e.g., B cells, dendritic cells, likely by passing through the gut barrier. High levels of immune protection have been established using this methodology. Such methods of delivery are useful for the aspects of the invention utilizing systemic delivery of antigen, nucleic acids, and/or other therapeutic agent.

In some aspects of the invention, the nucleic acids are administered along with therapeutic agents such as disorder-specific medicaments. As used herein, a disorder-specific medicament is a therapy or agent that is used predominately in the treatment or prevention of a disorder.

In one aspect, the combination of nucleic acid and disorder-specific medicaments allows for the administration of higher doses of disorder-specific medicaments without as many side effects as are ordinarily experienced at those high doses. In another aspect, the combination of nucleic acid and disorder-specific medicaments allows for the administration of lower, sub-therapeutic doses of either compound, but with higher efficacy than would otherwise be achieved using such low doses. As one example, by administering a combination of an immunostimulatory nucleic acid and a medicament, it is possible to achieve an effective response even though the medicament is administered at a dose which alone would not provide a therapeutic benefit (i.e., a sub-therapeutic dose). As another example, the combined administration achieves a response even though the nucleic acid is administered at a dose which alone would not provide a therapeutic benefit.

The nucleic acids and/or other therapeutic agents can also be administered on fixed schedules or in different temporal relationships to one another. The various combinations have many advantages over the prior art methods of modulating immune responses or

preventing or treating disorders, particularly with regard to decreased non-specific toxicity to normal tissues.

Cancer is a disease which involves the uncontrolled growth (i.e., division) of cells. Some of the known mechanisms which contribute to the uncontrolled proliferation of cancer cells include growth factor independence, failure to detect genomic mutation, and inappropriate cell signaling. The ability of cancer cells to ignore normal growth controls may result in an increased rate of proliferation. Although the causes of cancer have not been firmly established, there are some factors known to contribute, or at least predispose a subject, to cancer. Such factors include particular genetic mutations (e.g., BRCA gene mutation for breast cancer, APC for colon cancer), exposure to suspected cancer-causing agents, or carcinogens (e.g., asbestos, UV radiation) and familial disposition for particular cancers such as breast cancer.

The cancer may be a malignant or non-malignant cancer. Cancers or tumors include but are not limited to biliary tract cancer; brain cancer; breast cancer; cervical cancer; choriocarcinoma; colon cancer; endometrial cancer; esophageal cancer; gastric cancer; intraepithelial neoplasms; lymphomas; liver cancer; lung cancer (e.g., small cell and non-small cell); melanoma; neuroblastomas; oral cancer; ovarian cancer; pancreas cancer; prostate cancer; rectal cancer; sarcomas; skin cancer; testicular cancer; thyroid cancer; and renal cancer, as well as other carcinomas and sarcomas. In one embodiment the cancer is hairy cell leukemia, chronic myelogenous leukemia, cutaneous T-cell leukemia, multiple myeloma, follicular lymphoma, malignant melanoma, squamous cell carcinoma, renal cell carcinoma, prostate carcinoma, bladder cell carcinoma, or colon carcinoma.

A "subject having a cancer" is a subject that has detectable cancerous cells.

A "subject at risk of developing a cancer" is one who has a higher than normal probability of developing cancer. These subjects include, for instance, subjects having a genetic abnormality that has been demonstrated to be associated with a higher likelihood of developing a cancer, subjects having a familial disposition to cancer, subjects exposed to cancer-causing agents (i.e., carcinogens) such as tobacco, asbestos, or other chemical toxins, and subjects previously treated for cancer and in apparent remission.

A "cancer antigen" as used herein is a compound, such as a peptide or protein, associated with a tumor or cancer cell surface and which is capable of provoking an immune response when expressed on the surface of an antigen presenting cell in the context of an

MHC molecule. Cancer antigens can be prepared from cancer cells either by preparing crude extracts of cancer cells, for example, as described in Cohen PA et al. (1994) *Cancer Res* 54:1055-8, by partially purifying the antigens, by recombinant technology, or by de novo synthesis of known antigens. Cancer antigens include but are not limited to antigens that are recombinantly expressed, an immunogenic portion of, or a whole tumor or cancer. Such antigens can be isolated or prepared recombinantly or by any other means known in the art.

The terms "cancer antigen" and "tumor antigen" are used interchangeably and refer to antigens which are differentially expressed by cancer cells and can thereby be exploited in order to target cancer cells. Cancer antigens are antigens which can potentially stimulate apparently tumor-specific immune responses. Some of these antigens are encoded, although not necessarily expressed, by normal cells. These antigens can be characterized as those which are normally silent (i.e., not expressed) in normal cells, those that are expressed only at certain stages of differentiation and those that are temporally expressed such as embryonic and fetal antigens. Other cancer antigens are encoded by mutant cellular genes, such as oncogenes (e.g., activated *ras* oncogene), suppressor genes (e.g., mutant p53), fusion proteins resulting from internal deletions or chromosomal translocations. Still other cancer antigens can be encoded by viral genes such as those carried on RNA and DNA tumor viruses. Examples of tumor antigens include MAGE, MART-1/Melan-A, gp100, Dipeptidyl peptidase IV (DPPIV), adenosine deaminase-binding protein (ADAbp), cyclophilin b, Colorectal associated antigen (CRC)--C017-1A/GA733, Carcinoembryonic Antigen (CEA) and its immunogenic epitopes CAP-1 and CAP-2, etv6, aml1, Prostate Specific Antigen (PSA) and its immunogenic epitopes PSA-1, PSA-2, and PSA-3, prostate-specific membrane antigen (PSMA), T-cell receptor/CD3-zeta chain, MAGE-family of tumor antigens (e.g., MAGE-A1, MAGE-A2, MAGE-A3, MAGE-A4, MAGE-A5, MAGE-A6, MAGE-A7, MAGE-A8, MAGE-A9, MAGE-A10, MAGE-A11, MAGE-A12, MAGE-Xp2 (MAGE-B2), MAGE-Xp3 (MAGE-B3), MAGE-Xp4 (MAGE-B4), MAGE-C1, MAGE-C2, MAGE-C3, MAGE-C4, MAGE-C5), GAGE-family of tumor antigens (e.g., GAGE-1, GAGE-2, GAGE-3, GAGE-4, GAGE-5, GAGE-6, GAGE-7, GAGE-8, GAGE-9), BAGE, RAGE, LAGE-1, NAG, GnT-V, MUM-1, CDK4, tyrosinase, p53, MUC family, HER2/neu, p21ras, RCAS1, α-fetoprotein, E-cadherin, α-catenin, β-catenin and γ-catenin, p120ctn, gp100^{Pmel117}, PRAME, NY-ESO-1, cdc27, adenomatous polyposis coli protein (APC), fodrin, Connexin 37, Ig-idiotype, p15, gp75, GM2 and GD2 gangliosides, viral products such as human papilloma virus proteins,

Smad family of tumor antigens, lmp-1, P1A, EBV-encoded nuclear antigen (EBNA)-1, brain glycogen phosphorylase, SSX-1, SSX-2 (HOM-MEL-40), SSX-1, SSX-4, SSX-5, SCP-1 and CT-7, and c-erbB-2.

Cancers or tumors and tumor antigens associated with such tumors (but not exclusively), include acute lymphoblastic leukemia (etv6; aml1; cyclophilin b), B cell lymphoma (Ig-idiotype), glioma (E-cadherin; α-catenin; β-catenin; γ-catenin; p120ctn), bladder cancer (p21ras), biliary cancer (p21ras), breast cancer (MUC family; HER2/neu; c-erbB-2), cervical carcinoma (p53; p21ras), colon carcinoma (p21ras; HER2/neu; c-erbB-2; MUC family), colorectal cancer (Colorectal associated antigen (CRC)--C017-1A/GA733; APC), choriocarcinoma (CEA), epithelial cell cancer (cyclophilin b), gastric cancer (HER2/neu; c-erbB-2; ga733 glycoprotein), hepatocellular cancer (α-fetoprotein), Hodgkins lymphoma (lmp-1; EBNA-1), lung cancer (CEA; MAGE-3; NY-ESO-1), lymphoid cell-derived leukemia (cyclophilin b), melanoma (p15 protein, gp75, oncofetal antigen, GM2 and GD2 gangliosides), myeloma (MUC family; p21ras), non-small cell lung carcinoma (HER2/neu; c-erbB-2), nasopharyngeal cancer (lmp-1; EBNA-1), ovarian cancer (MUC family; HER2/neu; c-erbB-2), prostate cancer (Prostate Specific Antigen (PSA) and its immunogenic epitopes PSA-1, PSA-2, and PSA-3; PSMA; HER2/neu; c-erbB-2), pancreatic cancer (p21ras; MUC family; HER2/neu; c-erbB-2; ga733 glycoprotein), renal cancer (HER2/neu; c-erbB-2), squamous cell cancers of cervix and esophagus (viral products such as human papilloma virus proteins), testicular cancer (NY-ESO-1), T-cell leukemia (HTLV-1 epitopes), and melanoma (Melan-A/MART-1; cdc27; MAGE-3; p21ras; gp100^{Pmel117}).

For examples of tumor antigens which bind to either or both MHC class I and MHC class II molecules, see the following references: Coulie, *Stem Cells* 13:393-403, 1995; Traversari et al. *J Exp Med* 176:1453-1457, 1992; Chaux et al. *J Immunol* 163:2928-2936, 1999; Fujie et al. *Int J Cancer* 80:169-172, 1999; Tanzarella et al. *Cancer Res* 59:2668-2674, 1999; van der Bruggen et al. *Eur J Immunol* 24:2134-2140, 1994; Chaux et al. *J Exp Med* 189:767-778, 1999; Kawashima et al. *Hum Immunol* 59:1-14, 1998; Tahara et al. *Clin Cancer Res* 5:2236-2241, 1999; Gaugler et al. *J Exp Med* 179:921-930, 1994; van der Bruggen et al. *Eur J Immunol* 24:3038-3043, 1994; Tanaka et al. *Cancer Res* 57:4465-4468, 1997; Oiso et al. *Int J Cancer* 81:387-394, 1999; Herman et al. *Immunogenetics* 43:377-383, 1996; Manici et al. *J Exp Med* 189:871-876, 1999; Duffour et al. *Eur J Immunol* 29:3329-3337, 1999; Zorn et al. *Eur J Immunol* 29:602-607, 1999; Huang et al. *J Immunol*162:6849-6854, 1999; Boël et

al. *Immunity* 2:167-175, 1995; Van den Eynde et al. *J Exp Med* 182:689-698, 1995; De Backer et al. *Cancer Res* 59:3157-3165, 1999; Jäger et al. *J Exp Med* 187:265-270, 1998; Wang et al. *J Immunol* 161:3596-3606, 1998; Aarnoudse et al. *Int J Cancer* 82:442-448, 1999; Guilloux et al. *J Exp Med* 183:1173-1183, 1996; Lupetti et al. *J Exp Med* 188:1005-1016, 1998; Wölfel et al. *Eur J Immunol* 24:759-764, 1994; Skipper et al. *J Exp Med* 183:527-534, 1996; Kang et al. *J Immunol* 155:1343-1348, 1995; Morel et al. *Int J Cancer* 83:755-759, 1999; Brichard et al. *Eur J Immunol* 26:224-230, 1996; Kittlesen et al. *J Immunol* 160:2099-2106, 1998; Kawakami et al. *J Immunol* 161:6985-6992, 1998; Topalian et al. *J Exp Med* 183:1965-1971, 1996; Kobayashi et al. *Cancer Research* 58:296-301, 1998; Kawakami et al. *J Immunol* 154:3961-3968, 1995; Tsai et al. *J Immunol* 158:1796-1802, 1997; Cox et al. *Science* 264:716-719, 1994; Kawakami et al. *Proc Natl Acad Sci USA* 91:6458-6462, 1994; Skipper et al. *J Immunol* 157:5027-5033, 1996; Robbins et al. *J Immunol* 159:303-308, 1997; Castelli et al. *J Immunol* 162:1739-1748, 1999; Kawakami et al. *J Exp Med* 180:347-352, 1994; Castelli et al. *J Exp Med* 181:363-368, 1995; Schneider et al. *Int J Cancer* 75:451-458, 1998; Wang et al. *J Exp Med* 183:1131-1140, 1996; Wang et al. *J Exp Med* 184:2207-2216, 1996; Parkhurst et al. *Cancer Research* 58:4895-4901, 1998; Tsang et al. *J Natl Cancer Inst* 87:982-990, 1995; Correale et al. *J Natl Cancer Inst* 89:293-300, 1997; Coulie et al. *Proc Natl Acad Sci USA* 92:7976-7980, 1995; Wölfel et al. *Science* 269:1281-1284, 1995; Robbins et al. *J Exp Med* 183:1185-1192, 1996; Brändle et al. *J Exp Med* 183:2501-2508, 1996; ten Bosch et al. *Blood* 88:3522-3527, 1996; Mandruzzato et al. *J Exp Med* 186:785-793, 1997; Guéguen et al. *J Immunol* 160:6188-6194, 1998; Gjertsen et al. *Int J Cancer* 72:784-790, 1997; Gaudin et al. *J Immunol* 162:1730-1738, 1999; Chiari et al. *Cancer Res* 59:5785-5792, 1999; Hogan et al. *Cancer Res* 58:5144-5150, 1998; Pieper et al. *J Exp Med* 189:757-765, 1999; Wang et al. *Science* 284:1351-1354, 1999; Fisk et al. *J Exp Med* 181:2109-2117, 1995; Brossart et al. *Cancer Res* 58:732-736, 1998; Röpke et al. *Proc Natl Acad Sci USA* 93:14704-14707, 1996; Ikeda et al. *Immunity* 6:199-208, 1997; Ronsin et al. *J Immunol* 163:483-490, 1999; Vonderheide et al. *Immunity* 10:673-679, 1999. These antigens as well as others are disclosed in PCT Application PCT/US98/18601

The compositions and methods of the invention can be used alone or in conjunction with other agents and methods useful for the treatment of cancer. Cancer is currently treated using a variety of modalities including surgery, radiation therapy and chemotherapy. The choice of treatment modality will depend upon the type, location and dissemination of the

cancer. For example, surgery and radiation therapy may be more appropriate in the case of solid, well-defined tumor masses and less practical in the case of non-solid tumor cancers such as leukemia and lymphoma. One of the advantages of surgery and radiation therapy is the ability to control to some extent the impact of the therapy, and thus to limit the toxicity to normal tissues in the body. However, surgery and radiation therapy are often followed by chemotherapy to guard against any remaining or radio-resistant cancer cells. Chemotherapy is also the most appropriate treatment for disseminated cancers such as leukemia and lymphoma as well as metastases.

Chemotherapy refers to therapy using chemical and/or biological agents to attack cancer cells. Unlike localized surgery or radiation, chemotherapy is generally administered in a systemic fashion and thus toxicity to normal tissues is a major concern. Because many chemotherapy agents target cancer cells based on their proliferative profiles, tissues such as the gastrointestinal tract and the bone marrow which are normally proliferative are also susceptible to the effects of the chemotherapy. One of the major side effects of chemotherapy is myelosuppression (including anemia, neutropenia and thrombocytopenia) which results from the death of normal hemopoietic precursors.

Many chemotherapeutic agents have been developed for the treatment of cancer. Not all tumors, however, respond to chemotherapeutic agents and others although initially responsive to chemotherapeutic agents may develop resistance. As a result, the search for effective anti-cancer drugs has intensified in an effort to find even more effective agents with less non-specific toxicity.

Cancer medicaments function in a variety of ways. Some cancer medicaments work by targeting physiological mechanisms that are specific to tumor cells. Examples include the targeting of specific genes and their gene products (i.e., proteins primarily) which are mutated in cancers. Such genes include but are not limited to oncogenes (e.g., Ras, Her2, bcl-2), tumor suppressor genes (e.g., EGF, p53, Rb), and cell cycle targets (e.g., CDK4, p21, telomerase). Cancer medicaments can alternately target signal transduction pathways and molecular mechanisms which are altered in cancer cells. Targeting of cancer cells via the epitopes expressed on their cell surface is accomplished through the use of monoclonal antibodies. This latter type of cancer medicament is generally referred to herein as immunotherapy.

Other cancer medicaments target cells other than cancer cells. For example, some medicaments prime the immune system to attack tumor cells (i.e., cancer vaccines). Still other medicaments, called angiogenesis inhibitors, function by attacking the blood supply of solid tumors. Since the most malignant cancers are able to metastasize (i.e., exit the primary tumor site and seed a another site, thereby forming a secondary tumor), medicaments that impede this metastasis are also useful in the treatment of cancer. Angiogenic mediators include basic FGF, VEGF, angiopoietins, angiostatin, endostatin, TNF-α, TNP-470, thrombospondin-1, platelet factor 4, CAI, and certain members of the integrin family of proteins. One category of this type of medicament is a metalloproteinase inhibitor, which inhibits the enzymes used by the cancer cells to exist the primary tumor site and extravasate into another tissue.

Some cancer cells are antigenic and thus can be targeted by the immune system. In one aspect, the combined administration of nucleic acid and cancer medicaments, particularly those which are classified as cancer immunotherapies, is useful for stimulating a specific immune response against a cancer antigen.

The theory of immune surveillance is that a prime function of the immune system is to detect and eliminate neoplastic cells before a tumor forms. A basic principle of this theory is that cancer cells are antigenically different from normal cells and thus elicit immune reactions that are similar to those that cause rejection of immunologically incompatible allografts. Studies have confirmed that tumor cells differ, either qualitatively or quantitatively, in their expression of antigens. For example, "tumor-specific antigens" are antigens that are specifically associated with tumor cells but not normal cells. Examples of tumor specific antigens are viral antigens in tumors induced by DNA or RNA viruses. "Tumor-associated" antigens are present in both tumor cells and normal cells but are present in a different quantity or a different form in tumor cells. Examples of such antigens are oncofetal antigens (e.g., carcinoembryonic antigen), differentiation antigens (e.g., T and Tn antigens), and oncogene products (e.g., HER/neu).

Different types of cells that can kill tumor targets *in vitro* and *in vivo* have been identified: natural killer (NK) cells, cytolytic T lymphocytes (CTLs), lymphokine-activated killer cells (LAKs), and activated macrophages. NK cells can kill tumor cells without having been previously sensitized to specific antigens, and the activity does not require the presence of class I antigens encoded by the major histocompatibility complex (MHC) on target cells.

NK cells are thought to participate in the control of nascent tumors and in the control of metastatic growth. In contrast to NK cells, CTLs can kill tumor cells only after they have been sensitized to tumor antigens and when the target antigen is expressed on the tumor cells that also express MHC class I. CTLs are thought to be effector cells in the rejection of transplanted tumors and of tumors caused by DNA viruses. LAK cells are a subset of null lymphocytes distinct from the NK and CTL populations. Activated macrophages can kill tumor cells in a manner that is neither antigen-dependent nor MHC-restricted once activated. Activated macrophages are through to decrease the growth rate of the tumors they infiltrate. *In vitro* assays have identified other immune mechanisms such as antibody-dependent, cell-mediated cytotoxic reactions and lysis by antibody plus complement. However, these immune effector mechanisms are thought to be less important *in vivo* than the function of NK, CTLs, LAK, and macrophages *in vivo* (for review see Piessens WF et al. "Tumor Immunology", In: Scientific American Medicine, Vol. 2, Scientific American Books, N.Y., pp. 1-13, 1996).

The goal of immunotherapy is to augment a patient's immune response to an established tumor. One method of immunotherapy includes the use of adjuvants. Adjuvant substances derived from microorganisms, such as bacillus Calmette-Guérin, heighten the immune response and enhance resistance to tumors in animals.

Immunotherapeutic agents are medicaments which derive from antibodies or antibody fragments which specifically bind or recognize a cancer antigen. Antibody-based immunotherapies may function by binding to the cell surface of a cancer cell and thereby stimulate the endogenous immune system to attack the cancer cell. Another way in which antibody-based therapy functions is as a delivery system for the specific targeting of toxic substances to cancer cells. Antibodies are usually conjugated to toxins such as ricin (e.g., from castor beans), calicheamicin and maytansinoids, to radioactive isotopes such as Iodine-131 and Yttrium-90, to chemotherapeutic agents (as described herein), or to biological response modifiers. In this way, the toxic substances can be concentrated in the region of the cancer and non-specific toxicity to normal cells can be minimized. In addition to the use of antibodies which are specific for cancer antigens, antibodies which bind to vasculature, such as those which bind to endothelial cells, are also useful in the invention. This is because solid tumors generally are dependent upon newly formed blood vessels to survive, and thus most tumors are capable of recruiting and stimulating the growth of new blood vessels. As a

result, one strategy of many cancer medicaments is to attack the blood vessels feeding a tumor and/or the connective tissues (or stroma) supporting such blood vessels.

Cancer vaccines are medicaments which are intended to stimulate an endogenous immune response against cancer cells. Currently produced vaccines predominantly activate the humoral immune system (i.e., the antibody-dependent immune response). Other vaccines currently in development are focused on activating the cell-mediated immune system including cytotoxic T lymphocytes which are capable of killing tumor cells. Cancer vaccines generally enhance the presentation of cancer antigens to both antigen presenting cells (e.g., macrophages and dendritic cells) and/or to other immune cells such as T cells, B cells, and NK cells.

Although cancer vaccines may take one of several forms, as discussed infra, their purpose is to deliver cancer antigens and/or cancer associated antigens to antigen presenting cells (APC) in order to facilitate the endogenous processing of such antigens by APC and the ultimate presentation of antigen presentation on the cell surface in the context of MHC class I molecules. One form of cancer vaccine is a whole cell vaccine which is a preparation of cancer cells which have been removed from a subject, treated ex vivo and then reintroduced as whole cells in the subject. Lysates of tumor cells can also be used as cancer vaccines to elicit an immune response. Another form cancer vaccine is a peptide vaccine which uses cancer-specific or cancer-associated small proteins to activate T cells. Cancer-associated proteins are proteins which are not exclusively expressed by cancer cells (i.e., other normal cells may still express these antigens). However, the expression of cancer-associated antigens is generally consistently upregulated with cancers of a particular type. Other cancer vaccines include ganglioside vaccines, heat-shock protein vaccines, viral and bacterial vaccines, and nucleic acid vaccines.

Yet another form of cancer vaccine is a dendritic cell vaccine which includes whole dendritic cells which have been exposed to a cancer antigen or a cancer-associated antigen in vitro. Lysates or membrane fractions of dendritic cells may also be used as cancer vaccines. Dendritic cell vaccines are able to activate APCs directly. A dendritic cell is a professional APC. Dendritic cells form the link between the innate and the acquired immune system by presenting antigens and through their expression of pattern recognition receptors which detect microbial molecules like LPS in their local environment. Dendritic cells efficiently internalize, process, and present soluble specific antigen to which it is exposed. The process

of internalizing and presenting antigen causes rapid upregulation of the expression of major histocompatibility complex (MHC) and costimulatory molecules, the production of cytokines, and migration toward lymphatic organs where they are believed to be involved in the activation of T cells.

As used herein, chemotherapeutic agents embrace all other forms of cancer medicaments which do not fall into the categories of immunotherapeutic agents or cancer vaccines. Chemotherapeutic agents as used herein encompass both chemical and biological agents. These agents function to inhibit a cellular activity which the cancer cell is dependent upon for continued survival. Categories of chemotherapeutic agents include alkylating/alkaloid agents, antimetabolites, hormones or hormone analogs, and miscellaneous antineoplastic drugs. Most if not all of these agents are directly toxic to cancer cells and do not require immune stimulation.

An "infectious disease" or, equivalently, an "infection" as used herein, refers to a disorder arising from the invasion of a host, superficially, locally, or systemically, by an infectious organism. Infectious organisms include bacteria, viruses, fungi, and parasites. Accordingly, "infectious disease" includes bacterial infections, viral infections, fungal infections and parasitic infections.

A subject having an infectious disease is a subject that has been exposed to an infectious organism and has acute or chronic detectable levels of the organism in the body. Exposure to the infectious organism generally occurs with the external surface of the subject, e.g., skin or mucosal membranes and/or refers to the penetration of the external surface of the subject by the infectious organism.

A subject at risk of developing an infectious disease is a subject who has a higher than normal risk of exposure to an infection causing pathogen. For instance, a subject at risk may be a subject who is planning to travel to an area where a particular type of infectious agent is found or it may be a subject who through lifestyle or medical procedures is exposed to bodily fluids which may contain infectious organisms or directly to the organism or a subject living in an area where an infectious organism has been identified. Subjects at risk of developing an infectious disease also include general populations to which a medical agency recommends vaccination against a particular infectious organism.

A subject at risk of developing an infectious disease includes those subjects that have a general risk of exposure to a microorganism, e.g., influenza, but that do not have the active

disease during the treatment of the invention, as well as subjects that are considered to be at specific risk of developing an infectious disease because of medical or environmental factors that expose the subject to a particular microorganism.

Bacteria are unicellular organisms which multiply asexually by binary fission. They are classified and named based on their morphology, staining reactions, nutrition and metabolic requirements, antigenic structure, chemical composition, and genetic homology. Bacteria can be classified into three groups based on their morphological forms, spherical (coccus), straight-rod (bacillus) and curved or spiral rod (vibrio, campylobacter, spirillum, and spirochaete). Bacteria are also more commonly characterized based on their staining reactions into two classes of organisms, gram-positive and gram-negative. Gram refers to the method of staining which is commonly performed in microbiology labs. Gram-positive organisms retain the stain following the staining procedure and appear a deep violet color. Gram-negative organisms do not retain the stain but take up the counter-stain and thus appear pink.

Infectious bacteria include, but are not limited to, gram negative and gram positive bacteria. Gram positive bacteria include, but are not limited to *Pasteurella* species, *Staphylococci* species, and *Streptococcus* species. Gram negative bacteria include, but are not limited to, *Escherichia coli*, *Pseudomonas* species, and *Salmonella* species. Specific examples of infectious bacteria include but are not limited to: *Helicobacter pyloris*, *Borrelia burgdorferi*, *Legionella pneumophilia*, *Mycobacteria sps* (e.g., *M. tuberculosis*, *M. avium*, *M. intracellulare*, *M. kansasii*, *M. gordonae*), *Staphylococcus aureus*, *Neisseria gonorrhoeae*, *Neisseria meningitidis*, *Listeria monocytogenes*, *Streptococcus pyogenes* (Group A *Streptococcus*), *Streptococcus agalactiae* (Group B Streptococcus), *Streptococcus* (viridans group), *Streptococcus faecalis*, *Streptococcus bovis*, *Streptococcus* (anaerobic species), *Streptococcus pneumoniae*, pathogenic *Campylobacter sp.*, *Enterococcus sp.*, *Haemophilus influenzae*, *Bacillus anthracis*, *Corynebacterium diphtheriae*, *Corynebacterium sp.*, *Erysipelothrix rhusiopathiae*, *Clostridium perfringens*, *Clostridium tetani*, *Enterobacter aerogenes*, *Klebsiella pneumoniae*, *Pasturella multocida*, *Bacteroides sp.*, *Fusobacterium nucleatum*, *Streptobacillus moniliformis*, *Treponema pallidum*, *Treponema pertenue*, *Leptospira*, *Rickettsia*, and *Actinomyces israelli*.

Viruses are small infectious agents which generally contain a nucleic acid core and a protein coat, but are not independently living organisms. Viruses can also take the form of

infectious nucleic acids lacking a protein. A virus cannot survive in the absence of a living cell within which it can replicate. Viruses enter specific living cells either by endocytosis or direct injection of DNA (phage) and multiply, causing disease. The multiplied virus can then be released and infect additional cells. Some viruses are DNA-containing viruses and others are RNA-containing viruses. In some aspects, the invention also intends to treat diseases in which prions are implicated in disease progression such as for example bovine spongiform encephalopathy (i.e., mad cow disease, BSE) or scrapie infection in animals, or Creutzfeldt-Jakob disease in humans.

Viruses include, but are not limited to, enteroviruses (including, but not limited to, viruses that the family *picornaviridae*, such as polio virus, coxsackie virus, echo virus), rotaviruses, adenovirus, hepatitis virus. Specific examples of viruses that have been found in humans include but are not limited to: *Retroviridae* (e.g., human immunodeficiency viruses, such as HIV-1 (also referred to as HTLV-III, LAV or HTLV-III/LAV, or HIV-III; and other isolates, such as HIV-LP; *Picornaviridae* (e.g., polio viruses, hepatitis A virus; enteroviruses, human Coxsackie viruses, rhinoviruses, echoviruses); *Calciviridae* (e.g., strains that cause gastroenteritis); *Togaviridae* (e.g., equine encephalitis viruses, rubella viruses); *Flaviviridae* (e.g., dengue viruses, encephalitis viruses, yellow fever viruses); *Coronaviridae* (e.g., coronaviruses); *Rhabdoviridae* (e.g., vesicular stomatitis viruses, rabies viruses); *Filoviridae* (e.g., ebola viruses); *Paramyxoviridae* (e.g., parainfluenza viruses, mumps virus, measles virus, respiratory syncytial virus); *Orthomyxoviridae* (e.g., influenza viruses); *Bungaviridae* (e.g., Hantaan viruses, bunga viruses, phleboviruses and Nairo viruses); *Arenaviridae* (hemorrhagic fever viruses); *Reoviridae* (e.g., reoviruses, orbiviurses and rotaviruses); *Birnaviridae*; *Hepadnaviridae* (Hepatitis B virus); *Parvoviridae* (parvoviruses); *Papovaviridae* (papillomaviruses, polyoma viruses); *Adenoviridae* (most adenoviruses); *Herpesviridae* (herpes simplex virus (HSV) 1 and 2, varicella zoster virus, cytomegalovirus (CMV)); *Poxviridae* (variola viruses, vaccinia viruses, pox viruses); *Iridoviridae* (e.g., African swine fever virus); and unclassified viruses (e.g., the etiological agents of spongiform encephalopathies, the agent of delta hepatitis (thought to be a defective satellite of hepatitis B virus), the agents of non-A, non-B hepatitis (class 1 = internally transmitted; class 2 = parenterally transmitted (i.e., Hepatitis C); Norwalk and related viruses, and astroviruses).

Fungi are eukaryotic organisms, only a few of which cause infection in vertebrate mammals. Because fungi are eukaryotic organisms, they differ significantly from

prokaryotic bacteria in size, structural organization, life cycle and mechanism of multiplication. Fungi are classified generally based on morphological features, modes of reproduction and culture characteristics. Although fungi can cause different types of disease in subjects, such as respiratory allergies following inhalation of fungal antigens, fungal intoxication due to ingestion of toxic substances, such as *Amanita phalloides* toxin and phallotoxin produced by poisonous mushrooms and aflatoxins, produced by aspergillus species, not all fungi cause infectious disease.

Infectious fungi can cause systemic or superficial infections. Primary systemic infection can occur in normal healthy subjects, and opportunistic infections are most frequently found in immunocompromised subjects. The most common fungal agents causing primary systemic infection include *Blastomyces*, *Coccidioides*, and *Htoplasma*. Common fungi causing opportunistic infection in immunocompromised or immunosuppressed subjects include, but are not limited to, *Candida albicans, Cryptococcus neoformans*, and various *Aspergillus* species. Systemic fungal infections are invasive infections of the internal organs. The organism usually enters the body through the lungs, gastrointestinal tract, or intravenous catheters. These types of infections can be caused by primary pathogenic fungi or opportunistic fungi.

Superficial fungal infections involve growth of fungi on an external surface without invasion of internal tissues. Typical superficial fungal infections include cutaneous fungal infections involving skin, hair, or nails.

Diseases associated with fungal infection include aspergillosis, blastomycosis, candidiasis, chromoblastomycosis, coccidioidomycosis, cryptococcosis, fungal eye infections, fungal hair, nail, and skin infections, histoplasmosis, lobomycosis, mycetoma, otomycosis, paracoccidioidomycosis, disseminated *Penicillium marneffei*, phaeohyphomycosis, rhinosporidioisis, sporotrichosis, and zygomycosis.

Parasites are organisms which depend upon other organisms in order to survive and thus must enter, or infect, another organism to continue their life cycle. The infected organism, i.e., the host, provides both nutrition and habitat to the parasite. Although in its broadest sense the term parasite can include all infectious agents (i.e., bacteria, viruses, fungi, protozoa and helminths), generally speaking, the term is used to refer solely to protozoa, helminths, and ectoparasitic arthropods (e.g., ticks, mites, etc.). Protozoa are single-celled organisms which can replicate both intracellularly and extracellularly, particularly in the

blood, intestinal tract or the extracellular matrix of tissues. Helminths are multicellular organisms which almost always are extracellular (an exception being *Trichinella* spp.). Helminths normally require exit from a primary host and transmission into a secondary host in order to replicate. In contrast to these aforementioned classes, ectoparasitic arthropods form a parasitic relationship with the external surface of the host body.

Parasites include intracellular parasites and obligate intracellular parasites. Examples of parasites include but are not limited to *Plasmodium falciparum, Plasmodium ovale, Plasmodium malariae, Plasmdodium vivax, Plasmodium knowlesi, Babesia microti, Babesia divergens, Trypanosoma cruzi, Toxoplasma gondii, Trichinella spiralis, Leishmania major, Leishmania donovani, Leishmania braziliensis, Leishmania tropica, Trypanosoma gambiense, Trypanosoma rhodesiense* and *Schistosoma mansoni.*

Other medically relevant microorganisms have been described extensively in the literature, e.g., see C.G.A Thomas, *Medical Microbiology*, Bailliere Tindall, Great Britain 1983, the entire contents of which is hereby incorporated by reference. Each of the foregoing lists is illustrative and is not intended to be limiting.

The compositions and methods of the invention can be used alone or in conjunction with other agents and methods useful for the treatment of infection. Infection medicaments include but are not limited to anti-bacterial agents, anti-viral agents, anti-fungal agents and anti-parasitic agents. Phrases such as "anti-infective agent", "antibiotic", "anti-bacterial agent", "anti-viral agent", "anti-fungal agent", "anti-parasitic agent" and "parasiticide" have well-established meanings to those of ordinary skill in the art and are defined in standard medical texts. Briefly, anti-bacterial agents kill or inhibit bacteria, and include antibiotics as well as other synthetic or natural compounds having similar functions. Anti-viral agents can be isolated from natural sources or synthesized and are useful for killing or inhibiting viruses. Anti-fungal agents are used to treat superficial fungal infections as well as opportunistic and primary systemic fungal infections. Anti-parasite agents kill or inhibit parasites. Many antibiotics are low molecular weight molecules which are produced as secondary metabolites by cells, such as microorganisms. In general, antibiotics interfere with one or more functions or structures which are specific for the microorganism and which are not present in host cells.

One of the problems with anti-infective therapies is the side effects occurring in the host that is treated with the anti-infective agent. For instance, many anti-infectious agents can kill or inhibit a broad spectrum of microorganisms and are not specific for a particular

type of species. Treatment with these types of anti-infectious agents results in the killing of the normal microbial flora living in the host, as well as the infectious microorganism. The loss of the microbial flora can lead to disease complications and predispose the host to infection by other pathogens, since the microbial flora compete with and function as barriers to infectious pathogens. Other side effects may arise as a result of specific or non-specific effects of these chemical entities on non-microbial cells or tissues of the host.

Another problem with widespread use of anti-infectants is the development of antibiotic-resistant strains of microorganisms. Already, vancomycin-resistant *enterococci*, penicillin-resistant *pneumococci*, multi-resistant *S. aureus*, and multi-resistant *tuberculosis* strains have developed and are becoming major clinical problems. Widespread use of anti-infectants will likely produce many antibiotic-resistant strains of bacteria. As a result, new anti-infective strategies will be required to combat these microorganisms.

Antibacterial antibiotics which are effective for killing or inhibiting a wide range of bacteria are referred to as broad-spectrum antibiotics. Other types of antibacterial antibiotics are predominantly effective against the bacteria of the class gram-positive or gram-negative. These types of antibiotics are referred to as narrow-spectrum antibiotics. Other antibiotics which are effective against a single organism or disease and not against other types of bacteria, are referred to as limited-spectrum antibiotics.

Anti-bacterial agents are sometimes classified based on their primary mode of action. In general, anti-bacterial agents are cell wall synthesis inhibitors, cell membrane inhibitors, protein synthesis inhibitors, nucleic acid synthesis or functional inhibitors, and competitive inhibitors. Cell wall synthesis inhibitors inhibit a step in the process of cell wall synthesis, and in general in the synthesis of bacterial peptidoglycan. Cell wall synthesis inhibitors include β-lactam antibiotics, natural penicillins, semi-synthetic penicillins, ampicillin, clavulanic acid, cephalolsporins, and bacitracin.

The β-lactams are antibiotics containing a four-membered β-lactam ring which inhibits the last step of peptidoglycan synthesis. β-lactam antibiotics can be synthesized or natural. The β-lactam antibiotics produced by *penicillium* are the natural penicillins, such as penicillin G or penicillin V. These are produced by fermentation of *Penicillium chrysogenum*. The natural penicillins have a narrow spectrum of activity and are generally effective against *Streptococcus*, *Gonococcus*, and *Staphylococcus*. Other types of natural

penicillins, which are also effective against gram-positive bacteria, include penicillins F, X, K, and O.

Semi-synthetic penicillins are generally modifications of the molecule 6-aminopenicillanic acid produced by a mold. The 6-aminopenicillanic acid can be modified by addition of side chains which produce penicillins having broader spectrums of activity than natural penicillins or various other advantageous properties. Some types of semi-synthetic penicillins have broad spectrums against gram-positive and gram-negative bacteria, but are inactivated by penicillinase. These semi-synthetic penicillins include ampicillin, carbenicillin, oxacillin, azlocillin, mezlocillin, and piperacillin. Other types of semi-synthetic penicillins have narrower activities against gram-positive bacteria, but have developed properties such that they are not inactivated by penicillinase. These include, for instance, methicillin, dicloxacillin, and nafcillin. Some of the broad spectrum semi-synthetic penicillins can be used in combination with β-lactamase inhibitors, such as clavulanic acids and sulbactam. The β-lactamase inhibitors do not have anti-microbial action but they function to inhibit penicillinase, thus protecting the semi-synthetic penicillin from degradation.

One of the serious side effects associated with penicillins, both natural and semi-synthetic, is penicillin allergy. Penicillin allergies are very serious and can cause death rapidly. In a subject that is allergic to penicillin, the β-lactam molecule will attach to a serum protein which initiates an IgE-mediated inflammatory response. The inflammatory response leads to anaphylaxis and possibly death.

Another type of β-lactam antibiotic is the cephalolsporins. They are sensitive to degradation by bacterial β-lactamases, and thus, are not always effective alone. Cephalolsporins, however, are resistant to penicillinase. They are effective against a variety of gram-positive and gram-negative bacteria. Cephalolsporins include, but are not limited to, cephalothin, cephapirin, cephalexin, cefamandole, cefaclor, cefazolin, cefuroxine, cefoxitin, cefotaxime, cefsulodin, cefetamet, cefixime, ceftriaxone, cefoperazone, ceftazidine, and moxalactam.

Bacitracin is another class of antibiotics which inhibit cell wall synthesis, by inhibiting the release of muropeptide subunits or peptidoglycan from the molecule that delivers the subunit to the outside of the membrane. Although bacitracin is effective against

gram-positive bacteria, its use is limited in general to topical administration because of its high toxicity.

Carbapenems are another broad-spectrum β-lactam antibiotic, which is capable of inhibiting cell wall synthesis. Examples of carbapenems include, but are not limited to, imipenems. Monobactams are also broad-spectrum β-lactam antibiotics, and include, euztreonam. An antibiotic produced by *Streptomyces*, vancomycin, is also effective against gram-positive bacteria by inhibiting cell membrane synthesis.

Another class of anti-bacterial agents is the anti-bacterial agents that are cell membrane inhibitors. These compounds disorganize the structure or inhibit the function of bacterial membranes. One problem with anti-bacterial agents that are cell membrane inhibitors is that they can produce effects in eukaryotic cells as well as bacteria because of the similarities in phospholipids in bacterial and eukaryotic membranes. Thus these compounds are rarely specific enough to permit these compounds to be used systemically and prevent the use of high doses for local administration.

One clinically useful cell membrane inhibitor is Polymyxin. Polymyxins interfere with membrane function by binding to membrane phospholipids. Polymyxin is effective mainly against Gram-negative bacteria and is generally used in severe *Pseudomonas* infections or *Pseudomonas* infections that are resistant to less toxic antibiotics. The severe side effects associated with systemic administration of this compound include damage to the kidney and other organs.

Other cell membrane inhibitors include Amphotericin B and Nystatin which are anti-fungal agents used predominantly in the treatment of systemic fungal infections and *Candida* yeast infections. Imidazoles are another class of antibiotic that is a cell membrane inhibitor. Imidazoles are used as anti-bacterial agents as well as anti-fungal agents, e.g., used for treatment of yeast infections, dermatophytic infections, and systemic fungal infections. Imidazoles include but are not limited to clotrimazole, miconazole, ketoconazole, itraconazole, and fluconazole.

Many anti-bacterial agents are protein synthesis inhibitors. These compounds prevent bacteria from synthesizing structural proteins and enzymes and thus cause inhibition of bacterial cell growth or function or cell death. In general these compounds interfere with the processes of transcription or translation. Anti-bacterial agents that block transcription include but are not limited to Rifampins and Ethambutol. Rifampins, which inhibit the enzyme RNA

polymerase, have a broad spectrum activity and are effective against gram-positive and gram-negative bacteria as well as *Mycobacterium tuberculosis*. Ethambutol is effective against *Mycobacterium tuberculosis*.

Anti-bacterial agents which block translation interfere with bacterial ribosomes to prevent mRNA from being translated into proteins. In general this class of compounds includes but is not limited to tetracyclines, chloramphenicol, the macrolides (e.g., erythromycin) and the aminoglycosides (e.g., streptomycin).

The aminoglycosides are a class of antibiotics which are produced by the bacterium *Streptomyces,* such as, for instance streptomycin, kanamycin, tobramycin, amikacin, and gentamicin. Aminoglycosides have been used against a wide variety of bacterial infections caused by Gram-positive and Gram-negative bacteria. Streptomycin has been used extensively as a primary drug in the treatment of *tuberculosis*. Gentamicin is used against many strains of Gram-positive and Gram-negative bacteria, including *Pseudomonas* infections, especially in combination with Tobramycin. Kanamycin is used against many Gram-positive bacteria, including penicillin-resistant *Staphylococci*. One side effect of aminoglycosides that has limited their use clinically is that at dosages which are essential for efficacy, prolonged use has been shown to impair kidney function and cause damage to the auditory nerves leading to deafness.

Another type of translation inhibitor anti-bacterial agent is the tetracyclines. The tetracyclines are a class of antibiotics that are broad-spectrum and are effective against a variety of gram-positive and gram-negative bacteria. Examples of tetracyclines include tetracycline, minocycline, doxycycline, and chlortetracycline. They are important for the treatment of many types of bacteria but are particularly important in the treatment of Lyme disease. As a result of their low toxicity and minimal direct side effects, the tetracyclines have been overused and misused by the medical community, leading to problems. For instance, their overuse has led to widespread development of resistance.

Anti-bacterial agents such as the macrolides bind reversibly to the 50 S ribosomal subunit and inhibit elongation of the protein by peptidyl transferase or prevent the release of uncharged tRNA from the bacterial ribosome or both. These compounds include erythromycin, roxithromycin, clarithromycin, oleandomycin, and azithromycin. Erythromycin is active against most Gram-positive bacteria, *Neisseria*, *Legionella* and *Haemophilus*, but not against the *Enterobacteriaceae*. Lincomycin and clindamycin, which

block peptide bond formation during protein synthesis, are used against gram-positive bacteria.

Another type of translation inhibitor is chloramphenicol. Chloramphenicol binds the 70 S ribosome inhibiting the bacterial enzyme peptidyl transferase thereby preventing the growth of the polypeptide chain during protein synthesis. One serious side effect associated with chloramphenicol is aplastic anemia. Aplastic anemia develops at doses of chloramphenicol which are effective for treating bacteria in a small proportion (1/50,000) of patients. Chloramphenicol which was once a highly prescribed antibiotic is now seldom uses as a result of the deaths from anemia. Because of its effectiveness it is still used in life-threatening situations (e.g., typhoid fever).

Some anti-bacterial agents disrupt nucleic acid synthesis or function, e.g., bind to DNA or RNA so that their messages cannot be read. These include but are not limited to quinolones and co-trimoxazole, both synthetic chemicals and rifamycins, a natural or semi-synthetic chemical. The quinolones block bacterial DNA replication by inhibiting the DNA gyrase, the enzyme needed by bacteria to produce their circular DNA. They are broad spectrum and examples include norfloxacin, ciprofloxacin, enoxacin, nalidixic acid and temafloxacin. Nalidixic acid is a bactericidal agent that binds to the DNA gyrase enzyme (topoisomerase) which is essential for DNA replication and allows supercoils to be relaxed and reformed, inhibiting DNA gyrase activity. The main use of nalidixic acid is in treatment of lower urinary tract infections (UTI) because it is effective against several types of Gram-negative bacteria such as *E. coli*, *Enterobacter aerogenes*, *K. pneumoniae* and *Proteus* species which are common causes of UTI. Co-trimoxazole is a combination of sulfamethoxazole and trimethoprim, which blocks the bacterial synthesis of folic acid needed to make DNA nucleotides. Rifampicin is a derivative of rifamycin that is active against Gram-positive bacteria (including *Mycobacterium tuberculosis* and meningitis caused by *Neisseria meningitidis*) and some Gram-negative bacteria. Rifampicin binds to the beta subunit of the polymerase and blocks the addition of the first nucleotide which is necessary to activate the polymerase, thereby blocking mRNA synthesis.

Another class of anti-bacterial agents is compounds that function as competitive inhibitors of bacterial enzymes. The competitive inhibitors are mostly all structurally similar to a bacterial growth factor and compete for binding but do not perform the metabolic function in the cell. These compounds include sulfonamides and chemically modified forms

of sulfanilamide which have even higher and broader antibacterial activity. The sulfonamides (e.g., gantrisin and trimethoprim) are useful for the treatment of *Streptococcus pneumoniae*, beta-hemolytic *streptococci* and *E. coli*, and have been used in the treatment of uncomplicated UTI caused by *E. coli*, and in the treatment of meningococcal meningitis.

Anti-viral agents are compounds which prevent infection of cells by viruses or replication of the virus within the cell. There are many fewer antiviral drugs than antibacterial drugs because the process of viral replication is so closely related to DNA replication within the host cell, that non-specific antiviral agents would often be toxic to the host. There are several stages within the process of viral infection which can be blocked or inhibited by antiviral agents. These stages include, attachment of the virus to the host cell (immunoglobulin or binding peptides), uncoating of the virus (e.g. amantadine), synthesis or translation of viral mRNA (e.g. interferon), replication of viral RNA or DNA (e.g. nucleoside analogues), maturation of new virus proteins (e.g. protease inhibitors), and budding and release of the virus.

Another category of anti-viral agents are nucleoside analogues. Nucleoside analogues are synthetic compounds which are similar to nucleosides, but which have an incomplete or abnormal deoxyribose or ribose group. Once the nucleoside analogues are in the cell, they are phosphorylated, producing the triphosphate form which competes with normal nucleotides for incorporation into the viral DNA or RNA. Once the triphosphate form of the nucleoside analogue is incorporated into the growing nucleic acid chain, it causes irreversible association with the viral polymerase and thus chain termination. Nucleoside analogues include, but are not limited to, acyclovir (used for the treatment of herpes simplex virus and varicella-zoster virus), gancyclovir (useful for the treatment of cytomegalovirus), idoxuridine, ribavirin (useful for the treatment of respiratory syncitial virus), dideoxyinosine, dideoxycytidine, and zidovudine (azidothymidine).

Another class of anti-viral agents includes cytokines such as interferons. The interferons are cytokines which are secreted by virus-infected cells as well as immune cells. The interferons function by binding to specific receptors on cells adjacent to the infected cells, causing the change in the cell which protects it from infection by the virus. α and β-interferon also induce the expression of Class I and Class II MHC molecules on the surface of infected cells, resulting in increased antigen presentation for host immune cell recognition. α and β-interferons are available as recombinant forms and have been used for the treatment of

chronic hepatitis B and C infection. At the dosages which are effective for anti-viral therapy, interferons have severe side effects such as fever, malaise and weight loss.

Immunoglobulin therapy is used for the prevention of viral infection. Immunoglobulin therapy for viral infections is different from bacterial infections, because rather than being antigen-specific, the immunoglobulin therapy functions by binding to extracellular virions and preventing them from attaching to and entering cells which are susceptible to the viral infection. The therapy is useful for the prevention of viral infection for the period of time that the antibodies are present in the host. In general there are two types of immunoglobulin therapies, normal immune globulin therapy and hyper-immune globulin therapy. Normal immune globulin therapy utilizes a antibody product which is prepared from the serum of normal blood donors and pooled. This pooled product contains low titers of antibody to a wide range of human viruses, such as hepatitis A, parvovirus, enterovirus (especially in neonates). Hyper-immune globulin therapy utilizes antibodies which are prepared from the serum of individuals who have high titers of an antibody to a particular virus. Those antibodies are then used against a specific virus. Examples of hyper-immune globulins include zoster immune globulin (useful for the prevention of varicella in immunocompromised children and neonates), human rabies immune globulin (useful in the post-exposure prophylaxis of a subject bitten by a rabid animal), hepatitis B immune globulin (useful in the prevention of hepatitis B virus, especially in a subject exposed to the virus), and RSV immune globulin (useful in the treatment of respiratory syncitial virus infections).

Anti-fungal agents are useful for the treatment and prevention of infective fungi. Anti-fungal agents are sometimes classified by their mechanism of action. Some anti-fungal agents function as cell wall inhibitors by inhibiting glucose synthase. These include, but are not limited to, basiungin/ECB. Other anti-fungal agents function by destabilizing membrane integrity. These include, but are not limited to, imidazoles, such as clotrimazole, sertaconzole, fluconazole, itraconazole, ketoconazole, miconazole, and voriconacole, as well as FK 463, amphotericin B, BAY 38-9502, MK 991, pradimicin, UK 292, butenafine, and terbinafine. Other anti-fungal agents function by breaking down chitin (e.g., chitinase) or immunosuppression (501 cream).

Parasiticides are agents that kill parasites directly. Such compounds are known in the art and are generally commercially available. Examples of parasiticides useful for human administration include but are not limited to albendazole, amphotericin B, benznidazole,

bithionol, chloroquine HCl, chloroquine phosphate, clindamycin, dehydroemetine, diethylcarbamazine, diloxanide furoate, eflornithine, furazolidaone, glucocorticoids, halofantrine, iodoquinol, ivermectin, mebendazole, mefloquine, meglumine antimoniate, melarsoprol, metrifonate, metronidazole, niclosamide, nifurtimox, oxamniquine, paromomycin, pentamidine isethionate, piperazine, praziquantel, primaquine phosphate, proguanil, pyrantel pamoate, pyrimethanmine-sulfonamides, pyrimethanmine-sulfadoxine, quinacrine HCl, quinine sulfate, quinidine gluconate, spiramycin, stibogluconate sodium (sodium antimony gluconate), suramin, tetracycline, doxycycline, thiabendazole, tinidazole, trimethroprim-sulfamethoxazole, and tryparsamide.

The compositions and methods of the invention may also find use in the treatment of allergy and asthma.

An "allergy" refers to acquired hypersensitivity to a substance (allergen). Allergic conditions include but are not limited to eczema, allergic rhinitis or coryza, hay fever, allergic conjunctivitis, bronchial asthma, urticaria (hives) and food allergies, other atopic conditions including atopic dermatitis; anaphylaxis; drug allergy; and angioedema. Allergic diseases include but are not limited to rhinitis (hay fever), asthma, urticaria, and atopic dermatitis.

Allergy is a disease associated with the production of antibodies from a particular class of immunoglobulin, IgE, against allergens. The development of an IgE-mediated response to common aeroallergens is also a factor which indicates predisposition towards the development of asthma. If an allergen encounters a specific IgE which is bound to an IgE Fc receptor (FcεR) on the surface of a basophil (circulating in the blood) or mast cell (dispersed throughout solid tissue), the cell becomes activated, resulting in the production and release of mediators such as histamine, serotonin, and lipid mediators.

A subject having an allergy is a subject that is currently experiencing or has previously experienced an allergic reaction in response to an allergen.

A subject at risk of developing an allergy or asthma is a subject that has been identified as having an allergy or asthma in the past but who is not currently experiencing the active disease, as well as a subject that is considered to be at risk of developing asthma or allergy because of genetic or environmental factors. A subject at risk of developing allergy or asthma can also include a subject who has any risk of exposure to an allergen or a risk of developing asthma, i.e., someone who has suffered from an asthmatic attack previously or has a predisposition to asthmatic attacks. For instance, a subject at risk may be a subject who

is planning to travel to an area where a particular type of allergen or asthmatic initiator is found or it may even be any subject living in an area where an allergen has been identified. If the subject develops allergic responses to a particular antigen and the subject may be exposed to the antigen, i.e., during pollen season, then that subject is at risk of exposure to the antigen.

The generic name for molecules that cause an allergic reaction is allergen. An "allergen" as used herein is a molecule capable of provoking an immune response characterized by production of IgE. An allergen is a substance that can induce an allergic or asthmatic response in a susceptible subject. Thus, in the context of this invention, the term allergen means a specific type of antigen which can trigger an allergic response which is mediated by IgE antibody. The method and preparations of this invention extend to a broad class of such allergens and fragments of allergens or haptens acting as allergens. The list of allergens is enormous and can include pollens, insect venoms, animal dander, dust, fungal spores, and drugs (e.g., penicillin).

There are numerous species of allergens. The allergic reaction occurs when tissue-sensitizing immunoglobulin of the IgE type reacts with foreign allergen. The IgE antibody is bound to mast cells and/or basophils, and these specialized cells release chemical mediators (vasoactive amines) of the allergic reaction when stimulated to do so by allergens bridging the ends of the antibody molecule. Htamine, platelet activating factor, arachidonic acid metabolites, and serotonin are among the best known mediators of allergic reactions in man. Htamine and the other vasoactive amines are normally stored in mast cells and basophil leukocytes. The mast cells are dispersed throughout animal tissue and the basophils circulate within the vascular system. These cells manufacture and store histamine within the cell unless the specialized sequence of events involving IgE binding occurs to trigger its release.

The symptoms of the allergic reaction vary, depending on the location within the body where the IgE reacts with the antigen. If the reaction occurs along the respiratory epithelium, the symptoms are sneezing, coughing and asthmatic reactions. If the interaction occurs in the digestive tract, as in the case of food allergies, abdominal pain and diarrhea are common. Systemic reactions, for example following a bee sting, can be severe and often life-threatening.

Delayed-type hypersensitivity, also known as type IV allergy reaction, is an allergic reaction characterized by a delay period of at least 12 hours from invasion of the antigen into the allergic subject until appearance of the inflammatory or immune reaction. The T

lymphocytes (sensitized T lymphocytes) of individuals in an allergic condition react with the antigen, triggering the T lymphocytes to release lymphokines (macrophage migration inhibitory factor (MIF), macrophage activating factor (MAF), mitogenic factor (MF), skin-reactive factor (SRF), chemotactic factor, neovascularization-accelerating factor, etc.), which function as inflammation mediators, and the biological activity of these lymphokines, together with the direct and indirect effects of locally appearing lymphocytes and other inflammatory immune cells, give rise to the type IV allergy reaction. Delayed allergy reactions include tuberculin type reaction, homograft rejection reaction, cell-dependent type protective reaction, contact dermatitis hypersensitivity reaction, and the like, which are known to be most strongly suppressed by steroidal agents. Consequently, steroidal agents are effective against diseases which are caused by delayed allergy reactions. Long-term use of steroidal agents at concentrations currently being used can, however, lead to the serious side-effect known as steroid dependence. The methods of the invention solve some of these problems, by providing for lower and fewer doses to be administered.

Immediate hypersensitivity (or anaphylactic response) is a form of allergic reaction which develops very quickly, i.e., within seconds or minutes of exposure of the patient to the causative allergen, and it is mediated by IgE antibodies made by B lymphocytes. In nonallergic patients, there is no IgE antibody of clinical relevance; but, in a person suffering with allergic diseases, IgE antibody mediates immediate hypersensitivity by sensitizing mast cells which are abundant in the skin, lymphoid organs, in the membranes of the eye, nose and mouth, and in the respiratory tract and intestines.

Mast cells have surface receptors for IgE, and the IgE antibodies in allergy-suffering patients become bound to them. As discussed briefly above, when the bound IgE is subsequently contacted by the appropriate allergen, the mast cell is caused to degranulate and to release various substances called bioactive mediators, such as histamine, into the surrounding tissue. It is the biologic activity of these substances which is responsible for the clinical symptoms typical of immediate hypersensitivity; namely, contraction of smooth muscle in the airways or the intestine, the dilation of small blood vessels and the increase in their permeability to water and plasma proteins, the secretion of thick sticky mucus, and in the skin, redness, swelling and the stimulation of nerve endings that results in itching or pain.

"Asthma" as used herein refers to a disorder of the respiratory system characterized by inflammation, narrowing of the airways, and increased reactivity of the airways to inhaled

agents. Asthma is frequently, although not exclusively, associated with an atopic or allergic condition. Symptoms of asthma include recurrent episodes of wheezing, breathlessness, and chest tightness, and coughing, resulting from airflow obstruction. Airway inflammation associated with asthma can be detected through observation of a number of physiological changes, such as, denudation of airway epithelium, collagen deposition beneath basement membrane, edema, mast cell activation, inflammatory cell infiltration, including neutrophils, inosineophils, and lymphocytes. As a result of the airway inflammation, asthma patients often experience airway hyper-responsiveness, airflow limitation, respiratory symptoms, and disease chronicity. Airflow limitations include acute bronchoconstriction, airway edema, mucous plug formation, and airway remodeling, features which often lead to bronchial obstruction. In some cases of asthma, sub-basement membrane fibrosis may occur, leading to persistent abnormalities in lung function.

Research over the past several years has revealed that asthma likely results from complex interactions among inflammatory cells, mediators, and other cells and tissues resident in the airway. Mast cells, inosineophils, epithelial cells, macrophage, and activated T-cells all play an important role in the inflammatory process associated with asthma. Djukanovic R et al. (1990) *Am Rev Respir Dis* 142:434-457. It is believed that these cells can influence airway function through secretion of preformed and newly synthesized mediators which can act directly or indirectly on the local tissue. It has also been recognized that subpopulations of T-lymphocytes (Th2) play an important role in regulating allergic inflammation in the airway by releasing selective cytokines and establishing disease chronicity. Robinson DS et al. (1992) *N Engl J Med* 326:298-304.

Asthma is a complex disorder which arises at different stages in development and can be classified based on the degree of symptoms as acute, subacute or chronic. An acute inflammatory response is associated with an early recruitment of cells into the airway. The subacute inflammatory response involves the recruitment of cells as well as the activation of resident cells causing a more persistent pattern of inflammation. Chronic inflammatory response is characterized by a persistent level of cell damage and an ongoing repair process, which may result in permanent abnormalities in the airway.

A "subject having asthma" is a subject that has a disorder of the respiratory system characterized by inflammation, narrowing of the airways and increased reactivity of the airways to inhaled agents. Asthma is frequently, although not exclusively, associated with

atopic or allergic symptoms. An "initiator" as used herein refers to a composition or environmental condition which triggers asthma. Initiators include, but are not limited to, allergens, cold temperatures, exercise, viral infections, SO_2.

The compositions and methods of the invention can be used alone or in conjucnction with other agents and methods useful in the treatment of asthma. An "asthma/allergy medicament" as used herein is a composition of matter which reduces the symptoms of, prevents the development of, or inhibits an asthmatic or allergic reaction. Various types of medicaments for the treatment of asthma and allergy are described in the Guidelines For The Diagnosis and Management of Asthma, Expert Panel Report 2, NIH Publication No. 97/4051, July 19, 1997, the entire contents of which are incorporated herein by reference. The summary of the medicaments as described in the NIH publication is presented below. In most embodiments the asthma/allergy medicament is useful to some degree for treating both asthma and allergy.

Medications for the treatment of asthma are generally separated into two categories, quick-relief medications and long-term control medications. Asthma patients take the long-term control medications on a daily basis to achieve and maintain control of persistent asthma. Long-term control medications include anti-inflammatory agents such as corticosteroids, chromolyn sodium and nedocromil; long-acting bronchodilators, such as long-acting β_2-agonists and methylxanthines; and leukotriene modifiers. The quick-relief medications include short-acting β_2 agonists, anti-cholinergics, and systemic corticosteroids. There are many side effects associated with each of these drugs and none of the drugs alone or in combination is capable of preventing or completely treating asthma.

Asthma medicaments include, but are not limited, PDE-4 inhibitors, bronchodilator/beta-2 agonists, K+ channel openers, VLA-4 antagonists, neurokin antagonists, thromboxane A2 (TXA2) synthesis inhibitors, xanthines, arachidonic acid antagonists, 5 lipoxygenase inhibitors, TXA2 receptor antagonists, TXA2 antagonists, inhibitor of 5-lipox activation proteins, and protease inhibitors.

Bronchodilator/β_2 agonists are a class of compounds which cause bronchodilation or smooth muscle relaxation. Bronchodilator/β_2 agonists include, but are not limited to, salmeterol, salbutamol, albuterol, terbutaline, D2522/formoterol, fenoterol, bitolterol, pirbuerol methylxanthines and orciprenaline. Long-acting β_2 agonists and bronchodilators are compounds which are used for long-term prevention of symptoms in addition to the anti-

inflammatory therapies. Long-acting β_2 agonists include, but are not limited to, salmeterol and albuterol. These compounds are usually used in combination with corticosteroids and generally are not used without any inflammatory therapy. They have been associated with side effects such as tachycardia, skeletal muscle tremor, hypokalemia, and prolongation of QTc interval in overdose.

Methylxanthines, including for instance theophylline, have been used for long-term control and prevention of symptoms. These compounds cause bronchodilation resulting from phosphodiesterase inhibition and likely adenosine antagonism. Dose-related acute toxicities are a particular problem with these types of compounds. As a result, routine serum concentration must be monitored in order to account for the toxicity and narrow therapeutic range arising from individual differences in metabolic clearance. Side effects include tachycardia, tachyarrhythmias, nausea and vomiting, central nervous system stimulation, headache, seizures, hematemesis, hyperglycemia and hypokalemia. Short-acting β_2 agonists include, but are not limited to, albuterol, bitolterol, pirbuterol, and terbutaline. Some of the adverse effects associated with the administration of short-acting β_2 agonists include tachycardia, skeletal muscle tremor, hypokalemia, increased lactic acid, headache, and hyperglycemia.

Conventional methods for treating or preventing allergy have involved the use of anti-histamines or desensitization therapies. Anti-histamines and other drugs which block the effects of chemical mediators of the allergic reaction help to regulate the severity of the allergic symptoms but do not prevent the allergic reaction and have no effect on subsequent allergic responses. Desensitization therapies are performed by giving small doses of an allergen, usually by injection under the skin, in order to induce an IgG-type response against the allergen. The presence of IgG antibody helps to neutralize the production of mediators resulting from the induction of IgE antibodies, it is believed. Initially, the subject is treated with a very low dose of the allergen to avoid inducing a severe reaction and the dose is slowly increased. This type of therapy is dangerous because the subject is actually administered the compounds which cause the allergic response and severe allergic reactions can result.

Allergy medicaments include, but are not limited to, anti-histamines, steroids, and prostaglandin inducers. Anti-histamines are compounds which counteract histamine released by mast cells or basophils. These compounds are well known in the art and commonly used

for the treatment of allergy. Anti-histamines include, but are not limited to, astemizole, azelastine, betatastine, buclizine, ceterizine, cetirizine analogues, CS 560, desloratadine, ebastine, epinastine, fexofenadine, HSR 609, levocabastine, loratidine, mizolastine, norastemizole, terfenadine, and tranilast.

Prostaglandin inducers are compounds which induce prostaglandin activity. Prostaglandins function by regulating smooth muscle relaxation. Prostaglandin inducers include, but are not limited to, S-5751.

The asthma/allergy medicaments also include steroids and immunomodulators. The steroids include, but are not limited to, beclomethasone, fluticasone, triamcinolone, budesonide, corticosteroids and budesonide.

Corticosteroids include, but are not limited to, beclomethasome dipropionate, budesonide, flunisolide, fluticaosone propionate, and triamcinolone acetonide. Although dexamethasone is a corticosteroid having anti-inflammatory action, it is not regularly used for the treatment of asthma/allergy in an inhaled form because it is highly absorbed and it has long-term suppressive side effects at an effective dose. Dexamethasone, however, can be used according to the invention for the treating of asthma/allergy because when administered in combination with nucleic acids of the invention it can be administered at a low dose to reduce the side effects. Some of the side effects associated with corticosteroid include cough, dysphonia, oral thrush (candidiasis), and in higher doses, systemic effects, such as adrenal suppression, osteoporosis, growth suppression, skin thinning and easy bruising. Barnes & Peterson (1993) *Am Rev Respir Dis* 148:S1-S26; and Kamada AK et al.(1996) *Am J Respir Crit Care Med* 153:1739-48.

Systemic corticosteroids include, but are not limited to, methylprednisolone, prednisolone and prednisone. Cortosteroids are associated with reversible abnormalities in glucose metabolism, increased appetite, fluid retention, weight gain, mood alteration, hypertension, peptic ulcer, and aseptic necrosis of bone. These compounds are useful for short-term (3-10 days) prevention of the inflammatory reaction in inadequately controlled persistent asthma. They also function in a long-term prevention of symptoms in severe persistent asthma to suppress and control and actually reverse inflammation. Some side effects associated with longer term use include adrenal axis suppression, growth suppression, dermal thinning, hypertension, diabetes, Cushing's syndrome, cataracts, muscle weakness, and in rare instances, impaired immune function. It is recommended that these types of

compounds be used at their lowest effective dose (guidelines for the diagnosis and management of asthma; expert panel report to; NIH Publication No. 97-4051; July 1997).

The immunomodulators include, but are not limited to, the group consisting of anti-inflammatory agents, leukotriene antagonists, IL-4 muteins, soluble IL-4 receptors, immunosuppressants (such as tolerizing peptide vaccine), anti-IL-4 antibodies, IL-4 antagonists, anti-IL-5 antibodies, soluble IL-13 receptor-Fc fusion proteins, anti-IL-9 antibodies, CCR3 antagonists, CCR5 antagonists, VLA-4 inhibitors, and downregulators of IgE.

Leukotriene modifiers are often used for long-term control and prevention of symptoms in mild persistent asthma. Leukotriene modifiers function as leukotriene receptor antagonists by selectively competing for LTD-4 and LTE-4 receptors. These compounds include, but are not limited to, zafirlukast tablets and zileuton tablets. Zileuton tablets function as 5-lipoxygenase inhibitors. These drugs have been associated with the elevation of liver enzymes and some cases of reversible hepatitis and hyperbilirubinemia. Leukotrienes are biochemical mediators that are released from mast cells, inosineophils, and basophils that cause contraction of airway smooth muscle and increase vascular permeability, mucous secretions and activate inflammatory cells in the airways of patients with asthma.

Other immunomodulators include neuropeptides that have been shown to have immunomodulating properties. Functional studies have shown that substance P, for instance, can influence lymphocyte function by specific receptor-mediated mechanisms. Substance P also has been shown to modulate distinct immediate hypersensitivity responses by stimulating the generation of arachidonic acid-derived mediators from mucosal mast cells. McGillies J et al. (1987) *Fed Proc* 46:196-9 (1987). Substance P is a neuropeptide first identified in 1931. Von Euler and Gaddum *J Physiol (London)* 72:74-87 (1931). Its amino acid sequence was reported by Chang et al. in 1971. Chang MM et al. (1971) *Nature New Biol* 232:86-87. The immunoregulatory activity of fragments of substance P has been studied by Siemion IZ et al. (1990) *Molec Immunol* 27:887-890 (1990).

Another class of compounds is the down-regulators of IgE. These compounds include peptides or other molecules with the ability to bind to the IgE receptor and thereby prevent binding of antigen-specific IgE. Another type of downregulator of IgE is a monoclonal antibody directed against the IgE receptor-binding region of the human IgE molecule. Thus, one type of downregulator of IgE is an anti-IgE antibody or antibody fragment. Anti-IgE is

being developed by Genentech. One of skill in the art could prepare functionally active antibody fragments of binding peptides which have the same function. Other types of IgE downregulators are polypeptides capable of blocking the binding of the IgE antibody to the Fc receptors on the cell surfaces and displacing IgE from binding sites upon which IgE is already bound.

One problem associated with downregulators of IgE is that many molecules do not have a binding strength to the receptor corresponding to the very strong interaction between the native IgE molecule and its receptor. The molecules having this strength tend to bind irreversibly to the receptor. However, such substances are relatively toxic since they can bind covalently and block other structurally similar molecules in the body. Of interest in this context is that the α chain of the IgE receptor belongs to a larger gene family where, e.g., several of the different IgG Fc receptors are contained. These receptors are absolutely essential for the defense of the body against, e.g., bacterial infections. Molecules activated for covalent binding are, furthermore, often relatively unstable and therefore they probably have to be administered several times a day and then in relatively high concentrations in order to make it possible to block completely the continuously renewing pool of IgE receptors on mast cells and basophilic leukocytes.

Chromolyn sodium and nedocromil are used as long-term control medications for preventing primarily asthma symptoms arising from exercise or allergic symptoms arising from allergens. These compounds are believed to block early and late reactions to allergens by interfering with chloride channel function. They also stabilize mast cell membranes and inhibit activation and release of mediators from inosineophils and epithelial cells. A four to six week period of administration is generally required to achieve a maximum benefit.

Anticholinergics are generally used for the relief of acute bronchospasm. These compounds are believed to function by competitive inhibition of muscarinic cholinergic receptors. Anticholinergics include, but are not limited to, ipratropium bromide. These compounds reverse only cholinerigically-mediated bronchospasm and do not modify any reaction to antigen. Side effects include drying of the mouth and respiratory secretions, increased wheezing in some individuals, and blurred vision if sprayed in the eyes.

In addition to standard asthma/allergy medicaments, other methods for treating asthma/allergy have been used either alone or in combination with established medicaments. One preferred, but frequently impossible, method of relieving allergies is allergen or initiator

avoidance. Another method currently used for treating allergic disease involves the injection of increasing doses of allergen to induce tolerance to the allergen and to prevent further allergic reactions.

Allergen injection therapy (allergen immunotherapy) is known to reduce the severity of allergic rhinitis. This treatment has been theorized to involve the production of a different form of antibody, a protective antibody which is termed a "blocking antibody". Cooke RA et al. (1935) Serologic Evidence of Immunity with Coexisting Sensitization in a Type of Human Allergy, *Exp Med* 62:733. Other attempts to treat allergy involve modifying the allergen chemically so that its ability to cause an immune response in the patient is unchanged, while its ability to cause an allergic reaction is substantially altered. These methods, however, can take several years to be effective and are associated with the risk of side effects such as anaphylactic shock.

The compositions and methods of the invention can be used to modulate an immune response. The ability to modulate an immune response allows for the prevention and/or treatment of particular disorders that can be affected via immune system modulation.

Treatment after a disorder has started aims to reduce, ameliorate, or altogether eliminate the disorder, and/or its associated symptoms, or prevent it from becoming worse. Treatment of subjects before a disorder has started (i.e., prophylactic treatment) aims to reduce the risk of developing the disorder. As used herein, the term "prevent" refers to the prophylactic treatment of patients who are at risk of developing a disorder (resulting in a decrease in the probability that the subject will develop the disorder), and to the inhibition of further development of an already established disorder.

Different doses may be necessary for treatment of a subject, depending on activity of the compound, manner of administration, purpose of the immunization (i.e., prophylactic or therapeutic), nature and severity of the disorder, age and body weight of the subject. The administration of a given dose can be carried out both by single administration in the form of an individual dose unit or else several smaller dose units. Multiple administration of doses at specific intervals of weeks or months apart is usual for boosting antigen-specific immune responses.

Combined with the teachings provided herein, by choosing among the various active compounds and weighing factors such as potency, relative bioavailability, patient body weight, severity of adverse side-effects and preferred mode of administration, an effective

prophylactic or therapeutic treatment regimen can be planned which does not cause substantial toxicity and yet is entirely effective to treat the particular subject. The effective amount for any particular application can vary depending on such factors as the disease or condition being treated, the particular therapeutic agent being administered (e.g., in the case of an immunostimulatory nucleic acid, the type of nucleic acid, i.e., a CpG nucleic acid, the number of unmethylated CpG motifs or their location in the nucleic acid, the degree of modification of the backbone to the oligonucleotide, etc.), the size of the subject, or the severity of the disease or condition. One of ordinary skill in the art can empirically determine the effective amount of a particular nucleic acid and/or other therapeutic agent without necessitating undue experimentation.

Subject doses of the compounds described herein typically range from about 0.1 μg to 10,000 mg, more typically from about 1 μg/day to 8000 mg, and most typically from about 10 μg to 100 μg. Stated in terms of subject body weight, typical dosages range from about 0.1 μg to 20 mg/kg/day, more typically from about 1 to 10 mg/kg/day, and most typically from about 1 to 5 mg/kg/day.

The pharmaceutical compositions containing nucleic acids and/or other compounds can be administered by any suitable route for administering medications. A variety of administration routes are available. The particular mode selected will depend, of course, upon the particular agent or agents selected, the particular condition being treated, and the dosage required for therapeutic efficacy. The methods of this invention, generally speaking, may be practiced using any mode of administration that is medically acceptable, meaning any mode that produces effective levels of an immune response without causing clinically unacceptable adverse effects. Preferred modes of administration are discussed herein. For use in therapy, an effective amount of the nucleic acid and/or other therapeutic agent can be administered to a subject by any mode that delivers the agent to the desired surface, e.g., mucosal, systemic.

Administering the pharmaceutical composition of the present invention may be accomplished by any means known to the skilled artisan. Routes of administration include but are not limited to oral, parenteral, intravenous, intramuscular, intranasal, sublingual, intratracheal, inhalation, subcutaneous, ocular, vaginal, and rectal. For the treatment or prevention of asthma or allergy, such compounds are preferably inhaled, ingested or administered by systemic routes. Systemic routes include oral and parenteral. Inhaled

medications are preferred in some embodiments because of the direct delivery to the lung, the site of inflammation, primarily in asthmatic patients. Several types of devices are regularly used for administration by inhalation. These types of devices include metered dose inhalers (MDI), breath-actuated MDI, dry powder inhaler (DPI), spacer/holding chambers in combination with MDI, and nebulizers.

The therapeutic agents of the invention may be delivered to a particular tissue, cell type, or to the immune system, or both, with the aid of a vector. In its broadest sense, a "vector" is any vehicle capable of facilitating the transfer of the compositions to the target cells. The vector generally transports the immunostimulatory nucleic acid, antibody, antigen, and/or disorder-specific medicament to the target cells with reduced degradation relative to the extent of degradation that would result in the absence of the vector.

In general, the vectors useful in the invention are divided into two classes: biological vectors and chemical/physical vectors. Biological vectors and chemical/physical vectors are useful in the delivery and/or uptake of therapeutic agents of the invention.

Most biological vectors are used for delivery of nucleic acids and this would be most appropriate in the delivery of therapeutic agents that are or that include immunostimulatory nucleic acids.

In addition to the biological vectors discussed herein, chemical/physical vectors may be used to deliver therapeutic agents including immunostimulatory nucleic acids, antibodies, antigens, and disorder-specific medicaments. As used herein, a "chemical/physical vector" refers to a natural or synthetic molecule, other than those derived from bacteriological or viral sources, capable of delivering the nucleic acid and/or other medicament.

A preferred chemical/physical vector of the invention is a colloidal dispersion system. Colloidal dispersion systems include lipid-based systems including oil-in-water emulsions, micelles, mixed micelles, and liposomes. A preferred colloidal system of the invention is a liposome. Liposomes are artificial membrane vessels which are useful as a delivery vector *in vivo* or *in vitro*. It has been shown that large unilamellar vesicles (LUVs), which range in size from 0.2 - 4.0 μm can encapsulate large macromolecules. RNA, DNA and intact virions can be encapsulated within the aqueous interior and be delivered to cells in a biologically active form. Fraley et al. (1981) *Trends Biochem Sci* 6:77.

Liposomes may be targeted to a particular tissue by coupling the liposome to a specific ligand such as a monoclonal antibody, sugar, glycolipid, or protein. Ligands which

may be useful for targeting a liposome to an immune cell include, but are not limited to: intact or fragments of molecules which interact with immune cell specific receptors and molecules, such as antibodies, which interact with the cell surface markers of immune cells. Such ligands may easily be identified by binding assays well known to those of skill in the art. In still other embodiments, the liposome may be targeted to the cancer by coupling it to a one of the immunotherapeutic antibodies discussed earlier. Additionally, the vector may be coupled to a nuclear targeting peptide, which will direct the vector to the nucleus of the host cell.

Lipid formulations for transfection are commercially available from QIAGEN, for example, as EFFECTENE™ (a non-liposomal lipid with a special DNA condensing enhancer) and SUPERFECT™ (a novel acting dendrimeric technology).

Liposomes are commercially available from Gibco BRL, for example, as LIPOFECTIN™ and LIPOFECTACE™, which are formed of cationic lipids such as N-[1-(2, 3 dioleyloxy)-propyl]-N, N, N-trimethylammonium chloride (DOTMA) and dimethyl dioctadecylammonium bromide (DDAB). Methods for making liposomes are well known in the art and have been described in many publications. Liposomes also have been reviewed by Gregoriadis G (1985) *Trends Biotechnol* 3:235-241.

In one embodiment, the vehicle is a biocompatible microparticle or implant that is suitable for implantation or administration to the mammalian recipient. Exemplary bioerodible implants that are useful in accordance with this method are described in PCT International application no. PCT/US/03307 (Publication No. WO95/24929, entitled "Polymeric Gene Delivery System". PCT/US/0307 describes a biocompatible, preferably biodegradable polymeric matrix for containing an exogenous gene under the control of an appropriate promoter. The polymeric matrix can be used to achieve sustained release of the therapeutic agent in the subject.

The polymeric matrix preferably is in the form of a microparticle such as a microsphere (wherein the nucleic acid and/or the other therapeutic agent is dispersed throughout a solid polymeric matrix) or a microcapsule (wherein the nucleic acid and/or the other therapeutic agent is stored in the core of a polymeric shell). Other forms of the polymeric matrix for containing the therapeutic agent include films, coatings, gels, implants, and stents. The size and composition of the polymeric matrix device is selected to result in favorable release kinetics in the tissue into which the matrix is introduced. The size of the

polymeric matrix further is selected according to the method of delivery which is to be used, typically injection into a tissue or administration of a suspension by aerosol into the nasal and/or pulmonary areas. Preferably when an aerosol route is used the polymeric matrix and the nucleic acid and/or the other therapeutic agent are encompassed in a surfactant vehicle. The polymeric matrix composition can be selected to have both favorable degradation rates and also to be formed of a material which is bioadhesive, to further increase the effectiveness of transfer when the matrix is administered to a nasal and/or pulmonary surface that has sustained an injury. The matrix composition also can be selected not to degrade, but rather, to release by diffusion over an extended period of time. In some preferred embodiments, the nucleic acid are administered to the subject via an implant while the other therapeutic agent is administered acutely. Biocompatible microspheres that are suitable for delivery, such as oral or mucosal delivery, are disclosed in Chickering et al. (1996) *Biotech Bioeng* 52:96-101 and Mathiowitz E et al. (1997) *Nature* 386:410-414 and PCT Pat. Application WO97/03702.

Both non-biodegradable and biodegradable polymeric matrices can be used to deliver the nucleic acid and/or the other therapeutic agent to the subject. Biodegradable matrices are preferred. Such polymers may be natural or synthetic polymers. The polymer is selected based on the period of time over which release is desired, generally in the order of a few hours to a year or longer. Typically, release over a period ranging from between a few hours and three to twelve months is most desirable, particularly for the nucleic acid agents. The polymer optionally is in the form of a hydrogel that can absorb up to about 90% of its weight in water and further, optionally is cross-linked with multi-valent ions or other polymers.

Bioadhesive polymers of particular interest include bioerodible hydrogels described by H.S. Sawhney, C.P. Pathak and J.A. Hubell in *Macromolecules*, (1993) 26:581-587, the teachings of which are incorporated herein. These include polyhyaluronic acids, casein, gelatin, glutin, polyanhydrides, polyacrylic acid, alginate, chitosan, poly(methyl methacrylates), poly(ethyl methacrylates), poly(butylmethacrylate), poly(isobutyl methacrylate), poly(hexylmethacrylate), poly(isodecyl methacrylate), poly(lauryl methacrylate), poly(phenyl methacrylate), poly(methyl acrylate), poly(isopropyl acrylate), poly(isobutyl acrylate), and poly(octadecyl acrylate).

If the therapeutic agent is a nucleic acid, the use of compaction agents may also be desirable. Compaction agents also can be used alone, or in combination with, a biological or chemical/physical vector. A "compaction agent", as used herein, refers to an agent, such as a

histone, that neutralizes the negative charges on the nucleic acid and thereby permits compaction of the nucleic acid into a fine granule. Compaction of the nucleic acid facilitates the uptake of the nucleic acid by the target cell. The compaction agents can be used alone, i.e., to deliver a nucleic acid in a form that is more efficiently taken up by the cell or, more preferably, in combination with one or more of the above-described vectors.

Other exemplary compositions that can be used to facilitate uptake of a nucleic acid include calcium phosphate and other chemical mediators of intracellular transport, microinjection compositions, electroporation and homologous recombination compositions (e.g., for integrating a nucleic acid into a preselected location within the target cell chromosome).

The compounds may be administered alone (e.g., in saline or buffer) or using any delivery vectors known in the art. For instance the following delivery vehicles have been described: cochleates (Gould-Fogerite et al., 1994, 1996); Emulsomes (Vancott et al., 1998, Lowell et al., 1997); ISCOMs (Mowat et al., 1993, Carlsson et al., 1991, Hu et., 1998, Morein et al., 1999); liposomes (Childers et al., 1999, Michalek et al., 1989, 1992, de Haan 1995a, 1995b); live bacterial vectors (e.g., *Salmonella, Escherichia coli, Bacillus calmatte-guerin, Shigella, Lactobacillus*) (Hone et al., 1996, Pouwels et al., 1998, Chatfield et al., 1993, Stover et al., 1991, Nugent et al., 1998); live viral vectors (e.g., Vaccinia, adenovirus, Herpes Simplex) (Gallichan et al., 1993, 1995, Moss et al., 1996, Nugent et al., 1998, Flexner et al., 1988, Morrow et al., 1999); microspheres (Gupta et al., 1998, Jones et al., 1996, Maloy et al., 1994, Moore et al., 1995, O'Hagan et al., 1994, Eldridge et al., 1989); nucleic acid vaccines (Fynan et al., 1993, Kuklin et al., 1997, Sasaki et al., 1998, Okada et al., 1997, Ishii et al., 1997); polymers (e.g. carboxymethylcellulose, chitosan) (Hamajima et al., 1998, Jabbal-Gill et al., 1998); polymer rings (Wyatt et al., 1998); proteosomes (Vancott et al., 1998, Lowell et al., 1988, 1996, 1997); sodium fluoride (Hashi et al., 1998); transgenic plants (Tacket et al., 1998, Mason et al., 1998, Haq et al., 1995); virosomes (Gluck et al., 1992, Mengiardi et al., 1995, Cryz et al., 1998); and, virus-like particles (Jiang et al., 1999, Leibl et al., 1998).

The formulations of the invention are administered in pharmaceutically acceptable solutions, which may routinely contain pharmaceutically acceptable concentrations of salt, buffering agents, preservatives, compatible carriers, adjuvants, and optionally other therapeutic ingredients.

The term pharmaceutically-acceptable carrier means one or more compatible solid or liquid filler, diluents or encapsulating substances which are suitable for administration to a human or other vertebrate animal. The term carrier denotes an organic or inorganic ingredient, natural or synthetic, with which the active ingredient is combined to facilitate the application. The components of the pharmaceutical compositions also are capable of being commingled with the compounds of the present invention, and with each other, in a manner such that there is no interaction which would substantially impair the desired pharmaceutical efficiency.

For oral administration, the compounds (i.e., nucleic acids, antigens, antibodies, and other therapeutic agents) can be formulated readily by combining the active compound(s) with pharmaceutically acceptable carriers well known in the art. Such carriers enable the compounds of the invention to be formulated as tablets, pills, dragees, capsules, liquids, gels, syrups, slurries, suspensions and the like, for oral ingestion by a subject to be treated. Pharmaceutical preparations for oral use can be obtained as solid excipient, optionally grinding a resulting mixture, and processing the mixture of granules, after adding suitable auxiliaries, if desired, to obtain tablets or dragee cores. Suitable excipients are, in particular, fillers such as sugars, including lactose, sucrose, mannitol, or sorbitol; cellulose preparations such as, for example, maize starch, wheat starch, rice starch, potato starch, gelatin, gum tragacanth, methyl cellulose, hydroxypropylmethyl-cellulose, sodium carboxymethylcellulose, and/or polyvinylpyrrolidone (PVP). If desired, disintegrating agents may be added, such as the cross-linked polyvinyl pyrrolidone, agar, or alginic acid or a salt thereof such as sodium alginate. Optionally the oral formulations may also be formulated in saline or buffers for neutralizing internal acid conditions or may be administered without any carriers.

Dragee cores are provided with suitable coatings. For this purpose, concentrated sugar solutions may be used, which may optionally contain gum arabic, talc, polyvinyl pyrrolidone, carbopol gel, polyethylene glycol, and/or titanium dioxide, lacquer solutions, and suitable organic solvents or solvent mixtures. Dyestuffs or pigments may be added to the tablets or dragee coatings for identification or to characterize different combinations of active compound doses.

Pharmaceutical preparations which can be used orally include push-fit capsules made of gelatin, as well as soft, sealed capsules made of gelatin and a plasticizer, such as glycerol

or sorbitol. The push-fit capsules can contain the active ingredients in admixture with filler such as lactose, binders such as starches, and/or lubricants such as talc or magnesium stearate and, optionally, stabilizers. In soft capsules, the active compounds may be dissolved or suspended in suitable liquids, such as fatty oils, liquid paraffin, or liquid polyethylene glycols. In addition, stabilizers may be added. Microspheres formulated for oral administration may also be used. Such microspheres have been well defined in the art. All formulations for oral administration should be in dosages suitable for such administration.

For buccal administration, the compositions may take the form of tablets or lozenges formulated in conventional manner.

For administration by inhalation, the compounds for use according to the present invention may be conveniently delivered in the form of an aerosol spray presentation from pressurized packs or a nebulizer, with the use of a suitable propellant, *e.g.*, dichlorodifluoromethane, trichlorofluoromethane, dichlorotetrafluoroethane, carbon dioxide or other suitable gas. In the case of a pressurized aerosol the dosage unit may be determined by providing a valve to deliver a metered amount. Capsules and cartridges of *e.g.* gelatin for use in an inhaler or insufflator may be formulated containing a powder mix of the compound and a suitable powder base such as lactose or starch.

The compounds, when it is desirable to deliver them systemically, may be formulated for parenteral administration by injection, e.g., by bolus injection or continuous infusion. Formulations for injection may be presented in unit dosage form, *e.g.*, in ampoules or in multi-dose containers, with an added preservative. The compositions may take such forms as suspensions, solutions or emulsions in oily or aqueous vehicles, and may contain formulatory agents such as suspending, stabilizing and/or dispersing agents.

Pharmaceutical formulations for parenteral administration include aqueous solutions of the active compounds in water-soluble form. Additionally, suspensions of the active compounds may be prepared as appropriate oily injection suspensions. Suitable lipophilic solvents or vehicles include fatty oils such as sesame oil, or synthetic fatty acid esters, such as ethyl oleate or triglycerides, or liposomes. Aqueous injection suspensions may contain substances which increase the viscosity of the suspension, such as sodium carboxymethyl cellulose, sorbitol, or dextran. Optionally, the suspension may also contain suitable stabilizers or agents which increase the solubility of the compounds to allow for the preparation of highly concentrated solutions.

Alternatively, the active compounds may be in powder form for constitution with a suitable vehicle, e.g., sterile pyrogen-free water, before use.

The compounds may also be formulated in rectal or vaginal compositions such as suppositories or retention enemas, *e.g.*, containing conventional suppository bases such as cocoa butter or other glycerides.

In addition to the formulations described previously, the compounds may also be formulated as a depot preparation. Such long-acting formulations may be formulated with suitable polymeric or hydrophobic materials (for example as an emulsion in an acceptable oil) or ion exchange resins, or as sparingly soluble derivatives, for example, as a sparingly soluble salt.

The pharmaceutical compositions also may comprise suitable solid or gel phase carriers or excipients. Examples of such carriers or excipients include but are not limited to calcium carbonate, calcium phosphate, various sugars, starches, cellulose derivatives, gelatin, and polymers such as polyethylene glycols.

Suitable liquid or solid pharmaceutical preparation forms are, for example, aqueous or saline solutions for inhalation, microencapsulated, encochleated, coated onto microscopic gold particles, contained in liposomes, nebulized, aerosols, pellets for implantation into the skin, or dried onto a sharp object to be scratched into the skin. The pharmaceutical compositions also include granules, powders, tablets, coated tablets, (micro)capsules, suppositories, syrups, emulsions, suspensions, creams, drops or preparations with protracted release of active compounds, in whose preparation excipients and additives and/or auxiliaries such as disintegrants, binders, coating agents, swelling agents, lubricants, flavorings, sweeteners or solubilizers are customarily used as described above. The pharmaceutical compositions are suitable for use in a variety of drug delivery systems. For a brief review of methods for drug delivery, see Langer R (1990) *Science* 249:1527-1533, which is incorporated herein by reference.

The nucleic acids and optionally other therapeutics and/or antigens may be administered *per se* (neat) or in the form of a pharmaceutically acceptable salt. When used in medicine the salts should be pharmaceutically acceptable, but non-pharmaceutically acceptable salts may conveniently be used to prepare pharmaceutically acceptable salts thereof. Such salts include, but are not limited to, those prepared from the following acids: hydrochloric, hydrobromic, sulphuric, nitric, phosphoric, maleic, acetic, salicylic, p-toluene

sulphonic, tartaric, citric, methane sulphonic, formic, malonic, succinic, naphthalene-2-sulphonic, and benzene sulphonic. Also, such salts can be prepared as alkaline metal or alkaline earth salts, such as sodium, potassium or calcium salts of the carboxylic acid group.

Suitable buffering agents include: acetic acid and a salt (1-2% w/v); citric acid and a salt (1-3% w/v); boric acid and a salt (0.5-2.5% w/v); and phosphoric acid and a salt (0.8-2% w/v). Suitable preservatives include benzalkonium chloride (0.003-0.03% w/v); chlorobutanol (0.3-0.9% w/v); parabens (0.01-0.25% w/v) and thimerosal (0.004-0.02% w/v).

The compositions may conveniently be presented in unit dosage form and may be prepared by any of the methods well known in the art of pharmacy. All methods include the step of bringing the compounds into association with a carrier which constitutes one or more accessory ingredients. In general, the compositions are prepared by uniformly and intimately bringing the compounds into association with a liquid carrier, a finely divided solid carrier, or both, and then, if necessary, shaping the product. Liquid dose units are vials or ampoules. Solid dose units are tablets, capsules and suppositories.

Other delivery systems can include time-release, delayed release or sustained release delivery systems. Such systems can avoid repeated administrations of the compounds, increasing convenience to the subject and the physician. Many types of release delivery systems are available and known to those of ordinary skill in the art. They include polymer base systems such as poly(lactide-glycolide), copolyoxalates, polycaprolactones, polyesteramides, polyorthoesters, polyhydroxybutyric acid, and polyanhydrides. Microcapsules of the foregoing polymers containing drugs are described in, for example, U.S. Pat. No. 5,075,109. Delivery systems also include non-polymer systems that are: lipids including sterols such as cholesterol, cholesterol esters and fatty acids or neutral fats such as mono-, di-, and tri-glycerides; hydrogel release systems; silastic systems; peptide-based systems; wax coatings; compressed tablets using conventional binders and excipients; partially fused implants; and the like. Specific examples include, but are not limited to: (a) erosional systems in which an agent of the invention is contained in a form within a matrix such as those described in U.S. Pat. Nos. 4,452,775, 4,675,189, and 5,736,152, and (b) diffusional systems in which an active component permeates at a controlled rate from a polymer such as described in U.S. Pat. Nos. 3,854,480, 5,133,974 and 5,407,686. In addition, pump-based hardware delivery systems can be used, some of which are adapted for implantation.

The invention also provides efficient methods of identifying immunostimulatory compounds and optimizing the compounds and agents so identified. Generally, the screening methods involve assaying for compounds which inhibit or enhance signaling through a particular TLR. The methods employ a TLR, a suitable reference ligand for the TLR, and a candidate immunostimulatory compound. The selected TLR is contacted with a suitable reference compound (TLR ligand) and a TLR-mediated reference signal is measured. The selected TLR is also contacted with a candidate immunostimulatory compound and a TLR-mediated test signal is measured. The test signal and the reference signal are then compared. A favorable candidate immunostimulatory compound may subsequently be used as a reference compound in the assay. Such methods are adaptable to automated, high throughput screening of candidate compounds. Examples of such high throughput screening methods are described in U.S. Pat. Nos. 6,103,479; 6,051,380; 6,051,373; 5,998,152; 5,876,946; 5,708,158; 5,443,791; 5,429,921; and 5,143,854.

As used herein "TLR signaling" refers to an ability of a TLR polypeptide to activate the Toll/IL-1R (TIR) signaling pathway, also referred to herein as the TLR signal transduction pathway. Changes in TLR activity can be measured by assays designed to measure expression of genes under control of κB-sensitive promoters and enhancers. Such genes can be naturally occurring genes or they can be genes artificially introduced into a cell. Naturally occurring reporter genes include the genes encoding IL-1β, IL-6, IL-8, the p40 subunit of interleukin 12 (IL-12 p40), and the costimulatory molecules CD80 and CD86. Other genes can be placed under the control of such regulatory elements and thus serve to report the level of TLR signaling.

The assay mixture comprises a candidate immunostimulatory compound. Typically, a plurality of assay mixtures are run in parallel with different agent concentrations to obtain a different response to the various concentrations. Typically, one of these concentrations serves as a negative control, i.e., at zero concentration of agent or at a concentration of agent below the limits of assay detection. Candidate immunostimulatory compounds may encompass numerous chemical classes, although typically they are organic compounds. In some embodiments, the candidate immunostimulatory compounds are small RNAs or small organic compounds, i.e., organic compounds having a molecular weight of more than 50 yet less than about 2500 Daltons. Polymeric candidate immunostimulatory compounds can have higher molecular weights, e.g., oligonucleotides in the range of about 2500 to about 12,500.

Candidate immunostimulatory compounds also may be biomolecules such as nucleic acids, peptides, saccharides, fatty acids, sterols, isoprenoids, purines, pyrimidines, derivatives or structural analogs of the above, or combinations thereof and the like. Where the candidate immunostimulatory compound is a nucleic acid, the candidate immunostimulatory compound typically is a DNA or RNA molecule, although modified nucleic acids having non-natural bonds or subunits are also contemplated.

Candidate immunostimulatory compounds may be obtained from a wide variety of sources, including libraries of natural, synthetic, or semisynthetic compounds, or any combination thereof. For example, numerous means are available for random and directed synthesis of a wide variety of organic compounds and biomolecules, including expression of randomized oligonucleotides, synthetic organic combinatorial libraries, phage display libraries of random peptides, and the like. Alternatively, libraries of natural compounds in the form of bacterial, fungal, plant and animal extracts are available or readily produced. Additionally, natural and synthetically produced libraries and compounds can be readily modified through conventional chemical, physical, and biochemical means. Further, known pharmacological agents may be subjected to directed or random chemical modifications such as acylation, alkylation, esterification, amidification, etc., to produce structural analogs of the candidate immunostimulatory compounds.

A variety of other reagents also can be included in the mixture. These include reagents such as salts, buffers, neutral proteins (e.g., albumin), detergents, etc., which may be used to facilitate optimal protein-protein and/or protein-nucleic acid binding. Such a reagent may also reduce non-specific or background interactions of the reaction components. Other reagents that improve the efficiency of the assay such as protease inhibitors, nuclease inhibitors, antimicrobial agents, and the like may also be used.

The order of addition of components, incubation temperature, time of incubation, and other parameters of the assay may be readily determined. Such experimentation merely involves optimization of the assay parameters, not the fundamental composition of the assay. Incubation temperatures typically are between 4°C and 40°C, more typically about 37°C. Incubation times preferably are minimized to facilitate rapid, high throughput screening, and typically are between 1 minute and 10 hours.

After incubation, the level of TLR signaling is detected by any convenient method available to the user. For cell-free binding type assays, a separation step is often used to

separate bound from unbound components. The separation step may be accomplished in a variety of ways. For example, separation can be accomplished in solution, or, conveniently, at least one of the components is immobilized on a solid substrate, from which the unbound components may be easily separated. The solid substrate can be made of a wide variety of materials and in a wide variety of shapes, e.g., microtiter plate, microbead, dipstick, resin particle, etc. The substrate preferably is chosen to maximize signal-to-noise ratios, primarily to minimize background binding, as well as for ease of separation and cost.

Separation may be effected, for example, by removing a bead or dipstick from a reservoir, emptying or diluting a reservoir such as a microtiter plate well, rinsing a bead, particle, chromatographic column or filter with a wash solution or solvent. The separation step preferably includes multiple rinses or washes. For example, when the solid substrate is a microtiter plate, the wells may be washed several times with a washing solution, which typically includes those components of the incubation mixture that do not participate in specific bindings such as salts, buffer, detergent, non-specific protein, etc. Where the solid substrate is a magnetic bead, the beads may be washed one or more times with a washing solution and isolated using a magnet.

Detection may be effected in any convenient way for cell-based assays such as measurement of an induced polypeptide within, on the surface of, or secreted by the cell. Examples of detection methods useful in cell-based assays include fluorescence-activated cell sorting (FACS) analysis, bioluminescence, fluorescence, enzyme-linked immunosorbent assay (ELISA), reverse transcriptase-polymerase chain reaction (RT-PCR), and the like. Examples of detection methods useful in cell-free assays include bioluminescence, fluorescence, ELISA, RT-PCR, and the like.

Examples

Example 1. Responsiveness of Human PBMC to G,U-Containing Oligoribonucleotides.

Human peripheral blood mononuclear cells (PBMCs) were isolated from healthy donors, plated at 3×10^5 cells/well, stimulated in vitro with various test and control immunostimulatory agents for 16 hours, and then analyzed by enzyme-linked immunosorbent assay (ELISA) using matched antibody pairs from BD-Pharmingen for secreted cytokines IL-12 p40 and TNF-α, performed according to the manufacturer's protocol. Also included were certain negative controls, including medium alone and DOTAP (10 μg/200μl culture well;

"Liposomes") alone. The control immunostimulatory agents included the imidazoquinolone R-848 (2μg/ml), lipopolysaccharide (LPS; 1 μg/ml), Pam3Cys (5 μg/ml), poly IC (50 μg/ml), and CpG DNA (50 μg/ml). These are reported ligands for TLR7, TLR4, TLR2, TLR3, and TLR9, respectively. Test immunostimulatory agents included the following RNA molecules, each at 50 μg/ml, with and without DOTAP (10 μg total "with Liposomes" and "without Liposomes", respectively): GUGUUUAC alone; GUAGGCAC alone; GUGUUUAC in combination with GUAGGCAC; GUAGGA; GAAGGCAC; CUAGGCAC; CUCGGCAC; and CCCCCCCC. These RNA oligonucleotides each contained a phosphorothioate linkage between the penultimate and 3' terminal nucleoside.

FIG. 1 depicts the responsiveness of human PBMC to the test and control agents listed above, as measured by secreted amounts of IL-12 p40 (pg/ml). As can be seen in FIG. 1, PBMCs were responsive to R-848, LPS, Pam3Cys, and poly IC, while they were unresponsive to DOTAP alone. Significantly, human PBMC secreted large amounts of IL-12 p40 (10-20 ng/ml) in response to G,U-containing RNA oligonucleotides GUGUUUAC alone; GUAGGCAC alone; GUGUUUAC in combination with GUAGGCAC; CUAGGCAC; and CUCGGCAC, each in combination with DOTAP. Also significantly, human PBMC did not secrete significant amounts of IL-12 p40 in response to G,U-free RNA oligonucleotides GAAGGCAC and CCCCCCCC. The immunostimulatory effect of the G,U-containing RNA molecules appeared to be greatly enhanced by the inclusion of DOTAP. In this experiment, the G,U-containing 6-mer RNA GUAGGA appeared to exert little, if any immunostimulatory effect either with or without DOTAP.

FIG. 2 depicts the responsiveness of human PBMC to the test and control agents listed above, as measured by secreted amounts of TNF-α. A similar pattern of results was observed as in FIG. 1, i.e., human PBMC secreted large amounts of TNF-α (40-100 ng/ml) in response to G,U-containing RNA oligonucleotides GUGUUUAC alone; GUAGGCAC alone; GUGUUUAC in combination with GUAGGCAC; CUAGGCAC; and CUCGGCAC, each in combination with DOTAP. Also similar to the results in FIG. 1, human PBMC did not secrete significant amounts of TNF-α in response to G,U-free RNA oligonucleotides GAAGGCAC and CCCCCCCC, or in response to the G,U-containing 6-mer RNA GUAGGA. The immunostimulatory effect of the G,U-containing RNA molecules appeared to be greatly enhanced by the inclusion of DOTAP.

It will be appreciated in this example that the following partial self-complementarity basepairing is possible, where G-U wobble basepairs are shown joined with a dot and G-C and A-U basepairs are shown joined by a line:

```
   CUAGGCAC
   |·  ·|
CACGGAUC

   CUAGGCAC
   ||||
CACGGAUC

   CUCGGCAC
   |·  ·|
CACGGCUC

   CUCGGCAC
    ·||·
 CACGGCUC
```

Example 2. Dose-Response Behavior of Human PBMC to G,U-Containing Oligoribonucleotides.

The experiments described in the preceding example were repeated with varied concentrations of RNA oligonucleotides in order to assess the dose-response behavior of human PBMCs to G,U-containing RNA oligonucleotides of the invention. A total of 10, 3 or 1 μg RNA was added to 10 μg DOTAP and then added to the 200μl culture wells. After 16 hours IL-12 p40 and TNF-α ELISAs were performed as described in Example 1.

FIG. 3 depicts the dose-response of human PBMC to the various RNAs as measured by secreted amounts of IL-12 p40 (ng/ml). As can be seen from FIG. 3, human PBMC secreted increasing amounts of IL-12 p40 in response to increasing amounts of G,U-containing RNA oligomers GUGUUUAC; GUAGGCAC; CUAGGCAC; and CUCGGCAC, each in combination with DOTAP. Conversely, FIG. 3 also shows that human PBMC appeared not to secrete IL-12 p40 in response to any of the tested amounts of G,U-free RNA oligomers GAAGGCAC or CCCCCCCC.

Corresponding dose-response of human PBMC to the various RNAs was measured by secreted amounts of TNF-α. A similar pattern of results was observed as in FIG. 3, i.e.,

human PBMC secreted increasing amounts of TNF-α in response to increasing amounts G,U-containing RNA oligonucleotides GUGUUUAC; GUAGGCAC; CUAGGCAC; and CUCGGCAC, each in combination with DOTAP. Also similar to the results in FIG. 3, human PBMC did not appear to secrete significant amounts of TNF-α in response to any of the tested amounts of G,U-free RNA oligonucleotides GAAGGCAC and CCCCCCCC.

Example 3. Base Sequence Sensitivity of RNA Oligomers

Point mutations were made to the RNA oligonucleotide GUAGGCAC by substituting A or C at selected positions. The various oligoribonucleotides included the following: GUAGGCAC; GUAGGA; GAAGGCAC; AUAAACAC; AUAGACAC; AUAAGCAC; GUAAACAC; CUAGGCAC; CUCGGCAC; and GUGUUUAC. The oligonucleotides were titrated onto human PBMC isolated from healthy donors and plated at $3x10^5$ cells/well. A total of 10 μg RNA was added to 10 μg DOTAP and then added to the 200 μl culture wells. Human TNF-α was measured by ELISA using matched antibody pairs from BD-Pharmingen according to the manufacturer's protocol. Results are shown in **FIG. 4**.

Example 4. Effect of DOTAP on Human PBMC Response to Various Stimuli.

In order to characterize further the role of DOTAP in the immunostimulatory effects of the G,U-containing RNA oligomers observed in the previous examples, human PBMCs were isolated from healthy donors, plated at $3x10^5$ cells/well, and stimulated in the presence of known TLR ligands, either with or without DOTAP ("with Liposomes" or "without Liposomes", respectively). The known TLR ligands examined were total RNA prepared from hyphae (hyphae), total RNA prepared from yeast (yeast), total RNA prepared from promyelocytic cell line HL-60 (HL60), in vitro transcribed ribosomal RNA for *E. coli* Sp6, in vitro transcribed ribosomal RNA for *E. coli* T7, LPS, poly IC, Pam3Cys, and R-848. Medium alone and DOTAP alone were used as negative controls. The panel of RNAs from the previous examples, again at 10 μg/ml and without DOTAP, was also included.

Total RNA was isolated from the human promyelocytic cell line HL-60 using Trizol (Sigma). Prior to isolation, cells were treated for 4 hours with 500 μM hydrogen peroxide (H_2O_2), which induces apoptosis in this cell line (HL60 500). Untreated cells served as control (HL60 0).

Candida albicans RNA was isolated from yeast or hyphae (induced by 4h incubation with 10% fetal calf serum). Cells from a 100 ml culture were pelleted, washed and resuspended in 10 ml of Tris/EDTA buffer (10mM, 1mM). RNA was isolated by extraction with hot acidic phenol according to methods described in Ausubel FM et al., eds., Current Protocols in Molecular Biology, John Wiley & Sons, New York.

The genomic fragment of *E.coli* 16S RNA was amplified with the primers 5'-ATTGAAGAGTTTGATCATGGCTCAGATTGAACG-3' (SEQ ID NO:5) and 5'-TAAGGAGGTGATCCAACCGCAGGTTCC-3' (SEQ ID NO:6) from genomic *E.coli* DNA and cloned into the pGEM T easy vector. In vitro transcription was performed using T7 or Sp6 RNA polymerase. Transcribed RNA was further purified by chloroform/phenol extraction, precipitated, and used at 10 μg.

Following 16 hour incubation, ELISAs were performed as before to assess secretion of IL-12 p40 and TNF-α. Representative results are shown in FIG. 5.

FIG. 5 depicts the effect of DOTAP on the amount of IL-12 p40 secreted by human PBMC following incubation with and without DOTAP. As can be seen from the figure, the following stimuli appeared to exert greater immunostimultory effect in the presence of DOTAP than in its absence: hyphae, yeast, *E. coli* Sp6, and *E. coli* T7. The following stimuli appeared to exert reduced immunostimultory effect in the presence of DOTAP than in its absence: LPS, poly IC. The following stimuli appeared to exert about the same immunostimultory effect in the presence or absence of DOTAP: HL60, Pam3Cys and R-848.

Example 5. Immunostimulatory Effect of G,U-Containing RNA Oligomers Is Species- and MyD88-Dependent.

The following murine cells were isolated and incubated with various RNAs and other known TLR ligands in order to assess species-, cell type-, and signaling pathway- specificity: wild type macrophages in the presence of IFN-γ; MyD88-deficient macrophages in the presence of IFN-γ; J774 (mouse macrophage cell line); and RAW 264.7 (mouse macrophage cell line, e.g., ATCC TIB-71). Murine bone macrophages were generated from wild type or MyD88-deficient C57BL/6 mice by culturing bone marrow cells with 50 ng/ml M-CSF for 5 days. Cells were seeded at 25,000 cells/well and treated with 20 ng/ml IFN-γ for 16 hours. The murine macrophage cell lines RAW and J774 were seeded at 10,000 cells/well.

The following test and control agents were examined: R-848 (2 μg/ml), ODN 1668 (CpG DNA; 5'-TCCATGACGTTCCTGATGCT-3'; SEQ ID NO:7); LPS (1 μg/ml); poly IC (50 μg/ml); Pam3Cys (5 μg/ml); Ionomycin/TPA; the following RNA molecules, each with ("+ Lipo") and without DOTAP (10 μg/200 μl culture well): GUGUUUAC alone (RNA1); GUAGGCAC alone (RNA2); GUGUUUAC in combination with GUAGGCAC (RNA1/2); UCCGCAAUGGACGAAAGUCUGACGGA (RNA6; SEQ ID NO:8); GAGAUGGGUGCGAGAGCGUCAGUAUU (RNA9; SEQ ID NO:9); and the following DNA molecules, corresponding to RNA1, RNA2, and RNA1/2: GTGTTTAC alone (DNA1); GTAGGCAC alone (DNA2); and GTGTTTAC in combination with GTAGGCAC (DNA1/2). These RNA and DNA oligonucleotides each contained a phosphorothioate linkage between the penultimate and 3' terminal nucleoside. RNA6 and RNA9 each contained in addition a phosphorothioate linkage between the penultimate and 5' terminal nucleoside. RNA6 corresponds to a ribosomal RNA stem loop derived from *Listeria monocytogenes*. RNA9 corresponds to a stem loop derived from human immunodeficiency virus (HIV, an RNA retrovirus). The cells were cultured for 12 hours and supernatants were harvested. Murine IL-12 p40, IL-6, and TNF-α were measured by ELISA using matched antibody pairs from BD-Pharmingen according to the manufacturer's protocol. Representative results are shown in FIG. 6.

Panel A of **FIG. 6** shows that wild type murine macrophages in the presence of IFN-γ secrete significant amounts of IL-12 p40 in response to R-848; ODN 1668 (CpG DNA); LPS; poly IC; Pam3Cys; and G,U-containing RNA oligomers GUGUUUAC in combination with GUAGGCAC (with DOTAP). In contrast, Panel B of FIG. 6 shows that MyD88-deficient murine macrophages in the presence of IFN-γ secrete little or no IL-12 p40 in response to any of the test and control agents examined, thus demonstrating a dependence on MyD88 for immunostimulatory response to these compounds. Such a result is consistent with participation by a TLR in the immunostimulatory response to any of these compounds, including in particular the G,U-containing RNA oligonucleotides of the invention. Panels C and D of FIG. 6 show generally similar, if somewhat attenuated, response patterns of J774 and RAW 264.7 mouse macrophage cell lines as for wild type murine macrophages in the presence of IFN-γ, as shown in Panel A. Essentially similar results were found in parallel ELISAs measuring IL-6 and TNF-α.

In additional studies involving MyD88 wild-type cells, it was observed that addition of bafilomycin largely or completely abrogated the immunostimulatory effect of the RNA oligomers. Together with the MyD88-dependence, this observation is consistent with involvement of at least one of TLR3, TLR7, TLR8, and TLR9.

Example 6. Use of Cholesteryl Ester in Place of Cationic Lipid

In order to investigate the possibility of using cholesteryl ester-modified RNA oligomer in place of RNA oligomer plus cationic lipid, RNA oligomer GUGUGUGU was prepared with (R 1058) and without (R 1006) a 3′ cholesteryl ester modification. These two RNA oligomers with and without DOTAP, were added over a range of concentrations to overnight cultures of human PBMC. Culture supernatants were harvested, and human TNF-α, IL-12 p40, and IFN-α were measured by ELISA using matched antibody pairs from BD-Pharmingen according to the manufacturer's protocol. Representative results for experiments including DOTAP are shown in Table 1.

Table 1. Cholesteryl Ester Modification in Place of DOTAP

ID	TNF-α + DOTAP		TNF-α - DOTAP		IFN-α + DOTAP		IFN-α - DOTAP	
	EC50 µM	max pg/ml	EC50, µM	max pg/ml	EC50 µM	max pg/ml	EC50 µM	max pg/ml
R 1006	2.8	40000	7.8	2200	4.5	5000	--	--
R 1058	0.2	75000	1.0	3000	0.5	3800	0.5	1500

The results indicate that R 1058, with the cholesteryl ester modification, is more potent than R 1006, having the same base sequence but without cholesterol, both with and without DOTAP.

Example 7. Effect of Oligomer Length.

RNA oligomers GUGUGUGU, GUGUGUG, GUGUGU, GUGUG, GUGU, GUG, and GU, with and without DOTAP, were added over a range of concentrations to overnight cultures of human PBMC. Culture supernatants were harvested, and human TNF-α, IL-12 p40, and IFN-α were measured by ELISA using matched antibody pairs from BD-Pharmingen according to the manufacturer's protocol. Representative results for experiments including DOTAP are shown in Table 2.

Table 2. Effect of RNA Oligomer Length

ID	SEQ	TNF-α		IL-12 p40		IFN-α	
		EC50, μM	max pg/ml	EC50, μM	max pg/ml	EC50, μM	max pg/ml
R 1006	GUGUGUGU	2.8	40000	1.6	7000	4.5	5000
R 1048	GUGUGUG	2.2	30000	2.6	10000	4.6	2700
R 1049	GUGUGU	6.7	30000	2.1	8000	4.8	3400
R 1050	GUGUG	7.6	40000	3.9	14000	6.9	400
R 1051	GUGU	--	--	>20	14000	--	--
R 1052	GUG	--	--	>20	6000	5.5	800
R 1053	GU	--	--	>20	5000	--	--

<u>Example 8. Effect of Stabilization of Internucleoside Linkages.</u>

GUGUGUGU RNA oligomers were synthesized with specific phosphorothioate and phosphodiester linkages as shown in Table 2, where "*" represents phosphorothioate and "_" represents phosphodiester. RNA oligomers, with and without DOTAP, were added over a range of concentrations to overnight cultures of human PBMC. Culture supernatants were harvested, and human TNF-α, IL-12 p40, and IFN-α were measured by ELISA using matched antibody pairs from BD-Pharmingen according to the manufacturer's protocol. Representative results for experiments including DOTAP are shown in Table 3.

Table 3. Effect of Stabilization of Internucleoside Linkages

ID	SEQ	TNF-α		IFN-α	
		EC50, μM	max, pg/ml	EC50, μM	max, pg/ml
R 1006	G*U*G*U*G*U*G*U	2.8	40000	4.5	5000
R 1054	G*U_G*U*G*U*G*U	5.6	40000	6.7	3700
R 1055	G*U_G*U_G*U*G*U	>20	20000	--	--
R 1056	G*U_G*U_G*U_G*U	>20	12000	--	--
R 1057	G_U_G_U_G_U_G_U	--	--	0.1	6000

In like manner, an all-phosphodiester 40-mer capable of forming a stem-loop structure and having a base sequence as provided by 5′-CACACACUGCUUAAGCGCUUGCCUGCUUAAGUAGUGUGUG-3′ (R 1041; SEQ ID NO:10) was synthesized and tested in overnight culture with human PBMC. This RNA oligomer was found to be very potent in its ability to induce IFN-α, with an EC50 of <0.1 μM and a maximum of 5000 pg/ml.

Example 9. DNA:RNA Conjugates.

A series of DNA:RNA conjugates, each containing the RNA sequence GUGUGUGU and a poly-dT or a poly-dG sequence, was prepared. The oligomers were as follows, where again "*" represents phosphorothioate and "_" represents phosphodiester:

G*U*G*U*G*U*G*U_dG_dG*dG*dG*dG*dG (R 1060; SEQ ID NO:11)
dG*dG*dG*dG_dG_G*U*G*U*G*U*G*U (R 1061; SEQ ID NO:12)
G*U*G*U*G*U*G*U*dT*dT*dT*dT*dT*dT (R 1062; SEQ ID NO:13)
dT*dT*dT*dT*dT*G*U*G*U*G*U*G*U (R 1063; SEQ ID NO:14)

Human PBMC were cultured overnight in the presence of added DNA:RNA conjugate, with and without DOTAP. Culture supernatants were harvested and human TNF-α, IL-6, IL-12 p40, IP-10, and IFN-α were measured by ELISA using matched antibody pairs from BD-Pharmingen according to the manufacturer's protocol. Representative results for experiments including DOTAP are shown in Table 4.

Table 4. Immunostimulatory DNA:RNA Conjugates

ID	TNF-α		IL-6		IP-10	
	EC50, μM	max pg/ml	EC50, μM	max pg/ml	EC50, μM	max pg/ml
R 1060	4.9	20000	--	--	--	--
R 1061	4.3	20000	>20	10000	1.1	180
R 1062	0.3	80000	0.4	28000	0.1	400
R 1063	0.3	60000	0.8	28000	0.1	250

Example 10. Transfer RNA.

Human PBMC were cultured overnight in the presence of various concentrations (1, 3, and 10 μg/ml) of tRNA obtained from wheat germ, bovine, yeast, and *E. coli* sources, added to the culture medium with and without DOTAP. Culture supernatants were harvested and human TNF-α and IL-12 p40 were measured by ELISA using matched antibody pairs from BD-Pharmingen according to the manufacturer's protocol. Yeast and *E. coli* tRNAs, and to a lesser extent bovine tRNA, induced TNF-α and IL-12 p40 when DOTAP was also present. In addition, *E. coli* tRNA at 3 and 10 μg/ml induced minor amounts of both cytokines even without DOTAP.

Example 11. HIV RNA.

Human PBMC were incubated overnight with either of two key G,U-rich sequences, namely 5'-GUAGUGUGUG-3' (SEQ ID NO:2) and 5'-GUCUGUUGUGUG-3' (SEQ ID NO:3), corresponding to nt 99-108 and 112-123 of HIV-1 strain BH10, respectively, each with and without DOTAP. Culture supernatants were harvested, and human IL-12 p40 and TNF-α were measured by ELISA using matched antibody pairs from BD-Pharmingen according to the manufacturer's protocol. Representative results are shown in FIG. 7. The figure shows that both of these RNA molecules, at micromolar concentrations in the presence of DOTAP, induced 50-100 ng/ml of TNF and 50-200 ng/ml of IL-12 p40.

Example 12. Responsiveness of Human PBMC to Stringent Response Factor.

When bacteria are starved they enter into a programmed response termed the stringent response. This involves the production of nucleic acid alarmones and ribosomal loss. Bacteria growing at high rates contain 70,000-80,000 ribosomes accounting for as much as 50% of their dry weight. As growth slows, unneeded ribosomes are hydrolyzed. It was hypothesized that rapidly growing cells in their early stationary phase contain large amounts of oligoribonucleotides that are released into the media when the cells enter a neutral pH environment.

FIG. 10 depicts the responsiveness of human PBMC to stringent response factor (SRF). SRF is produced by rapidly growing bacteria (in this case *Listeria monocytogenes*) in rich media until their late log phase. The bacteria were pelleted and resuspended in an equal volume of PBS for 24h. The mixture is centrifuged to remove the bacteria. The supernatant

is sterilized by passing it through a 0.2 μm filter. The sterilized solution was passed through a molecular filter with a cutoff of 10 kDa. This fraction was separated on a C18 column and the eluant was tested. At a concentration of 5 μg/ml SRF induced TNF from human PBMC. If SRF was treated with any of three RNAses the activity was destroyed. The activity was not due to substances other than RNA because the RNase-treated SRF had near background stimulatory ability. This implied activity was due to RNA.

Example 13. Responsiveness of Human PBMC to Ribonucleoside Vanadyl Complexes.

During studies of SRF it was surprisingly determined that the RNAse inhibitor, ribonucleoside vanadyl complexes (RVCs), could stimulate human PBMC to produce TNF (**FIG. 11**) and IL-6.

FIG. 11 depicts the responsiveness of human PBMC to the ribonucleoside vanadyl complexes (RVCs). It was unexpectedly discovered during testing of RNAse inhibitors that RVCs were stimulatory for human PBMC. 2mM RVC induced the release of substantial TNF. Also tested was the anti-viral imidazoquinoline, resiquimod (R-848) denoted as X and used at 0.1 μg/ml.

Example 14. Responsiveness of Human TLR7 and human TLR8 to Ribonucleosides.

The observations of Example 13 could be extended to 293 cells genetically reconstituted with TLR7 and TLR8 but not non-transfected 293 cells (**FIG. 12**). During analysis of individual ribonucleoside vanadyl complexes, it was unexpectedly determined that a mixture of the ribonucleosides A, U, C, and G or the single ribonucleoside G was effective in the absence of vanadate at stimulating PBMC to produce TNF and TLR7 or TLR8 to activate NF-kB (**FIG. 12**).

FIG. 12 depicts the responsiveness of human TLR7 and human TLR8 to ribonucleosides. It was determined that the response by human PBMC to RNA or RVC was mediated by TLR7 or TLR8 and further that the response could be driven by ribonucleosides only. Human 293 cells were either mock-transfected or transfected with human TLR7 or human TLR8 and monitored for responsiveness to ribonucleosides. The open reading frames of human TLR7 (hTLR7) and human TLR8 (hTLR8) were amplified by PCR from a cDNA library of human PBMC using the following primers pairs: for TLR7, 5'-CACCTCTCATGCTCTGCTCTCTTC-3' (SEQ ID NO:15) and

5'-GCTAGACCGTTTCCTTGAACACCTG-3' (SEQ ID NO:16); and for TLR8, 5'-CTGCGCTGCTGCAAGTTACGGAATG-3' (SEQ ID NO:17) and 5'-GCGCGAAATCATGACTTAACGTCAG-3' (SEQ ID NO:18). The sequence information for primer selection was obtained from Genbank accession numbers AF240467 and AF245703. All full-length TLR fragments were cloned into pGEM-T Easy vector (Promega, Mannheim, Germany), excised with NotI, cloned into the expression vector pcDNA 3.1(-) (Invitrogen, Karlsruhe, Germany) and sequenced. Sequences of the coding region of hTLR7 and hTLR8 correspond to the accession numbers AF240467 (SEQ ID NO:25) and AF245703, respectively (SEQ ID NO:29).

For monitoring transient NF-κB activation, $3x10^6$ 293 HEK cells (ATCC, VA, USA) were electroporated at 200 volt and 960μF with 1μg TLR expression plasmid, 20 ng NF-κB luciferase reporter-plasmid and 14μg of pcDNA3.1(-) plasmid as carrier in 400 μl RPMI medium supplemented with 25% fetal bovine serum (FCS). Cells were seeded at 10^5 cells per well and after over night culture stimulated with R-848 (denoted in **FIG. 12** as X; commercially synthesized by GLSynthesis Inc., Worcester, MA, USA), RVCs or ribonucleosides for a further 7 hours. Stimulated cells were lysed using reporter lysis buffer (Promega, Mannheim, Germany), and lysate was assayed for luciferase activity using a Berthold luminometer (Wildbad, Germany).

As depicted in **FIG. 12**, TLR7 transfectants responded to R-848, RVCs, a mixture of ribonucleosides (A, G, C, U at 0.5 mM) and the ribonucleoside guanosine. Likewise TLR8 showed a similar response pattern.

<u>Example 16. Responsiveness of TLR7 and TLR8 to Mixtures of Two Ribonucleosides.</u>

FIG. 13 depicts the responsiveness of TLR7 and TLR8 to mixtures of two ribonucleosides. In an experiment conducted as in **FIG. 11** it was determined that TLR 8 responded best to a combination of the ribonucleosides G and U, however, TLR7 responded best to G alone. Additionally it can be seen that a minor response was given by a combination of C and U. These data show that ribonucleosides of the proper composition serve as ligands for TLR7 and TLR8. The nonspecific stimulus of TPA served as a control only. X denotes R-848.

<u>Example 17. Human PBMC Respond to a Mixture of the Ribonucleosides G and U.</u>

FIG. 14 depicts the response of human PBMC to a mixture of the ribonucleosides G and U. It can be appreciated that the ribonucleosides G and U act synergistically to induce TNF from human PBMC. In this example the ratio of G:U of 1:10 was optimal.

Example 18. Human PBMC Respond to G,U-Rich Oligoribonucleotides.

FIG. 15 depicts how human PBMC respond to RNA G,U-rich oligonucleotides. Both RNA and DNA oligonucleotides 5'-GUUGUGGUUGUGGUUGUG-3' (SEQ ID NOs:1 and 19) were tested at 30μM on human PBMC and TNF was monitored. Human PBMC were responsive to G,U-rich RNA oligonucleotides and not G,U-rich DNA oligonucleotides.

Example 19. Human PBMC Respond to Oxidized RNA.

FIG. 16 depicts the response of human PBMC to oxidized RNA. Ribosomal 16S RNA was isolated from *E. coli* and subjected to chemical oxidation. The treatments were (mod A) 0.2 mM ascorbic acid plus 0.2 mM $CuCl_2$ for 30 min at 37°C or (mod B) 0.2 mM ascorbic acid plus 0.02 mM $CuCl_2$ for 30 min at 37°C. This treatment induces oxidation at the 8 position of guanosine and also induces strand breaks 3' of the modified guanosine. It was shown that ribosomal RNA induced TNF production from human PBMC. It was also evident that oxidation of ribosomal RNA greatly potentiates the response.

Example 20. Human TLR7 Responds to Oxidized Guanosine Ribonucleoside.

FIG. 17 depicts human TLR7 and TLR8 responses to the oxidized guanosine ribonucleoside. Cells mock-transfected or transfected with human TLR 7 or human TLR8, as in Example 14, were tested for responsiveness to 7-allyl-8-oxoguanosine (loxoribine) at 1 mM. It can be clearly shown that human TLR7 is responsive to 7-allyl-8-oxoguanosine. Thus it appears that a ligand for TLR 7 is oxidized nucleic acids.

Example 21. Human TLR7 Responds to Other Modified Guanosine Ribonucleoside.

FIG. 18 depicts human TLR7 responses to the other modified guanosine ribonucleoside. Cells transfected with human TLR7, as in Example 14, were tested for a dose-dependent response to 7-allyl-8-oxoguanosine (loxoribine). Additionally other modified guanosines were tested. It can be clearly shown that human TLR 7 was responsive to 7-allyl-8-oxoguanosine in a dose-dependent manor. As shown above, human TLR7 was

responsive to guanosine; however **FIG. 18** also shows that human TLR7 responded mildly to the deoxy form of guanosine as well as to 8-bromo-guanosine.

Example 22. Distribution of Human TLRs.

FIG. 19 depicts the distribution of human TLR1-TLR9. Various purified human immune cells were screened by PCR for TLR1 through 9 expression. It was shown that human lymphoid CD123+ dendritic cells (DC) were strongly positive for TLR9 and TLR7 while weaker for TLR8. The converse was shown however for myeloid CD11c+ DC. This is very relevant because the two types of DC have very different functions in the immune system. Significantly, **FIG. 19** also shows that human neutrophils were strongly positive for human TLR8 while very weak for TLR9 and negative for TLR7. This is also relevant because neutrophils are very often the first cells to engage infectious pathogens and thus believed to initiate responses.

Example 23.

HEK-293 cell were stably transfected with human TLR7 or human TLR8. Additionally, the cells were stably transfected with NF-κB-luciferase reporter construct. The cells were titrated with varing amounts of RNA oligonucleotides and cultured for 16h. Luciferase activity was measured by standard methods and normalizied versus mock-stimulated transfectants. Luciferase activity measured for the mock-stimulated transfectant was set to a value of 1-fold NF-κB induction. Results are shown in **FIG. 20**, where old NF-κB induced by the stimulating RNA oligonucleotide is plotted versus the concentration of test ribonucleotide. Stimulation with GUGUGUGU is shown for human TLR8. Stimulation with GUAGUCAC is shown for human TLR7 and human TLR8.

Equivalents

The foregoing written specification is considered to be sufficient to enable one skilled in the art to practice the invention. The present invention is not to be limited in scope by examples provided, since the examples are intended as a single illustration of one aspect of the invention and other functionally equivalent embodiments are within the scope of the invention. Various modifications of the invention in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description and fall

within the scope of the appended claims. The advantages and objects of the invention are not necessarily encompassed by each embodiment of the invention.

All references, patents and patent publications that are recited in this application are incorporated in their entirety herein by reference.

We claim:

Claims

1. An immunostimulatory composition, comprising:
an isolated RNA oligomer 5-40 nucleotides long having a base sequence comprising at least one guanine (G) and at least one uracil (U), and optionally
a cationic lipid.

2. The composition of claim 1, wherein the isolated RNA oligomer is a G,U-rich RNA.

3. The composition of claim 1, wherein the base sequence comprises 5′-RURGY-3′, wherein R represents purine, U represents uracil, G represents guanine, and Y represents pyrimidine.

4. The composition of claim 1, wherein the base sequence comprises 5′-GUAGU-3′, wherein A represents adenine.

5. The composition of claim 1, wherein the base sequence comprises 5′-GUAGUGU-3′.

6. The composition of claim 1, wherein the base sequence comprises 5′-GUUGB-3′, wherein B represents U, G, or C, wherein C represents cytosine.

7. The composition of claim 1, wherein the base sequence comprises 5′-GUGUG-3′.

8. The composition of claim 1, wherein the base sequence comprises 5'-GUGUUUAC-3'.

9. The composition of claim 1, wherein the base sequence comprises 5'-GUAGGCAC-3'.

10. The composition of claim 1, wherein the base sequence comprises 5'-CUAGGCAC-3'.

11. The composition of claim 1, wherein the base sequence comprises 5'-CUCGGCAC-3'.

12. The composition of claim 1, wherein the oligomer is 5-12 nucleotides long.

13. The composition of claim 1, wherein the base sequence is free of CpG dinucleotide.

14. The composition of claim 1, wherein the base sequence is at least 50 percent self-complementary.

15. The composition of claim 1, wherein the oligomer is a plurality of oligomers.

16. The composition of claim 15, wherein the plurality of oligomers comprises an oligomer having a first base sequence and an oligomer having a second base sequence, wherein the first base sequence and the second base sequence are at least 50 percent complementary.

17. The composition of claim 15, wherein the plurality of oligomers comprises an oligomer having a base sequence comprising 5'-GUGUUUAC-3' and an oligomer having a base sequence comprising 5'-GUAGGCAC-3'.

18. The composition of claim 1, wherein the oligomer comprises a non-natural backbone linkage.

19. The composition of claim 18, wherein the non-natural backbone linkage is a phosphorothiate linkage.

20. The composition of claim 1, wherein the oligomer comprises a modified base selected from the group consisting of 7-deazaguanosine, 8-azaguanosine, 5-methyluracil, and pseudouracil.

21. The composition of claim 1, wherein the oligomer comprises a modified sugar.

22. The composition of claim 1, wherein the cationic lipid is N-[1-(2,3-dioleoyloxy)propyl]-N,N,N-trimethylammonium methyl-sulfate (DOTAP).

23. The composition of claim 1, further comprising an antigen.

24. The composition of claim 23, wherein the antigen is an allergen.

25. The composition of claim 23, wherein the antigen is a cancer antigen.

26. The composition of claim 23, wherein the antigen is a microbial antigen.

27. The composition of claim 1, further comprising a pharmaceutically acceptable carrier.

28. A method of activating an immune cell, comprising:
contacting an immune cell with the composition of any one of claims 1-27 in an effective amount to induce activation of the immune cell.

29. The method of claim 28, wherein the activation of the immune cell comprises secretion of a cytokine or chemokine by the immune cell.

30. The method of claim 29, wherein the cytokine is selected from the group consisting of interleukin 6 (IL-6), interleukin 12 (IL-12), an interferon (IFN), and tumor necrosis factor (TNF).

31. The method of claim 29, wherein the chemokine is interferon-gamma-inducible protein 10 (IP-10).

32. The method of claim 28, wherein the activation of the immune cell comprises activation of a MyD88-dependent signal transduction pathway.

33. The method of claim 32, wherein the MyD88-dependent signal transduction pathway is associated with a Toll-like receptor (TLR).

34. The method of claim 33, wherein the TLR is TLR8.

35. The method of claim 33, wherein the TLR is TLR7.

36. A method of inducing an immune response in a subject, comprising:
administering to a subject a composition of any one of claims 1-27 in an effective amount to induce an immune response in the subject.

37. The method of claim 36, wherein the subject has or is at risk of having a cancer.

38. The method of claim 36, wherein the subject has or is at risk of having an infection with an agent selected from the group consisting of viruses, bacteria, fungi, and parasites.

39. The method of claim 36, wherein the subject has or is at risk of having a viral infection.

40. A method of inducing an immune response in a subject, comprising:
administering to a subject an antigen; and
administering to the subject a composition of any one of claims 1-22 or 27 in an effective amount to induce an immune response to the antigen.

41. The method of claim 40, wherein the antigen is an allergen.

42. The method of claim 40, wherein the antigen is a cancer antigen.

43. The method of claim 40, wherein the antigen is a microbial antigen.

44. A method of inducing an immune response in a subject, comprising:
isolating dendritic cells of a subject;
contacting the dendritic cells ex vivo with the composition of any one of claims 1-22 or 27;

contacting the dendritic cells ex vivo with an antigen; and
administering the contacted dendritic cells to the subject.

45. The method of claim 44, wherein the antigen is an allergen.

46. The method of claim 44, wherein the antigen is a cancer antigen.

47. The method of claim 44, wherein the antigen is a microbial antigen.

48. A composition, comprising:
an effective amount of a ligand for Toll-like receptor 8 (TLR8) to induce TLR8 signaling, and
an effective amount of a ligand for a second TLR selected from the group consisting of: TLR1, TLR2, TLR3, TLR4, TLR5, TLR6, TLR7, TLR9 and TLR10 to induce signaling by the second TLR.

49. The composition according to claim 48, wherein the second TLR is TLR3.

50. The composition according to claim 48, wherein the second TLR is TLR7.

51. The composition according to claim 48, wherein the second TLR is TLR9.

52. The composition according to claim 48, wherein the ligand for TLR8 and the ligand for the second TLR are linked.

53. The composition according to claim 48, further comprising a pharmaceutically acceptable carrier.

54. A composition, comprising:
an effective amount of a ligand for TLR7 to induce TLR7 signaling, and

an effective amount of a ligand for a second TLR selected from the group consisting of: TLR1, TLR2, TLR3, TLR4, TLR5, TLR6, TLR8, TLR9, and TLR10 to induce signaling by the second TLR.

55. The composition according to claim 54, wherein the second TLR is TLR3.

56. The composition according to claim 54, wherein the second TLR is TLR8.

57. The composition according to claim 54, wherein the second TLR is TLR9.

58. The composition according to claim 54, wherein the ligand for TLR7 and the ligand for the second TLR are linked.

59. The composition according to claim 54, further comprising a pharmaceutically acceptable carrier.

60. A composition, comprising:

a DNA:RNA conjugate, wherein DNA of the conjugate comprises a CpG motif effective for stimulating TLR9 signaling and RNA of the conjugate comprises RNA effective for stimulating signaling by TLR3, TLR7, TLR8, or any combination thereof.

61. The composition according to claim 60, wherein the conjugate comprises a chimeric DNA:RNA backbone.

62. The composition according to claim 61, wherein the chimeric backbone comprises a cleavage site between the DNA and the RNA.

63. The composition according to claim 60, wherein the conjugate comprises a double-stranded DNA:RNA heteroduplex.

64. The composition according to claim 60, further comprising a pharmaceutically acceptable carrier.

65. A method for stimulating TLR8 signaling, comprising:
contacting TLR8 with an isolated RNA in an effective amount to stimulate TLR8 signaling.

66. The method according to claim 65, wherein the RNA is double-stranded RNA.

67. The method according to claim 65, wherein the RNA is ribosomal RNA.

68. The method according to claim 65, wherein the RNA is transfer RNA.

69. The method according to claim 65, wherein the RNA is messenger RNA.

70. The method according to claim 65, wherein the RNA is viral RNA.

71. The method according to claim 65, wherein the RNA is G,U-rich RNA.

72. The method according to claim 65, wherein the RNA consists essentially of G and U.

73. A method for stimulating TLR8 signaling, comprising:
contacting TLR8 with a mixture of nucleosides consisting essentially of G and U in a ratio between 1G:50U and 10G:1U, in an amount effective to stimulate TLR8 signaling.

74. The method according to claim 73, wherein the nucleosides are ribonucleosides.

75. The method according to claim 73, wherein the nucleosides comprise a mixture of ribonucleosides and deoxyribonucleosides.

76. The method according to claim 73, wherein the G is a guanosine derivative selected from the group consisting of: 8-bromoguanosine, 8-oxoguanosine, 8-mercaptoguanosine, 7-allyl-8-oxoguanosine, guanosine ribonucleoside vanadyl complex, inosine, and nebularine.

77. A method for stimulating TLR8 signaling, comprising:
contacting TLR8 with a mixture of ribonucleoside vanadyl complexes.

78. The method according to claim 77, wherein the mixture comprises guanosine ribonucleoside vanadyl complexes.

79. A method for stimulating TLR8 signaling, comprising:
contacting TLR8 with an isolated G,U-rich oligonucleotide comprising a sequence selected from the group consisting of: UUGUGG, UGGUUG, GUGUGU, and GGGUUU, in an amount effective to stimulate TLR8 signaling.

80. The method according to claim 79, wherein the oligonucleotide is an oligoribonucleotide.

81. The method according to claim 79, wherein the oligonucleotide is 7-50 bases long.

82. The method according to claim 79, wherein the oligonucleotide is 12-24 bases long.

83. The method according to claim 79, wherein the oligonucleotide has a sequence 5′-GUUGUGGUUGUGGUUGUG-3′ (SEQ ID NO:1).

84. A method for stimulating TLR8 signaling, comprising:
contacting TLR8 with an at least partially double-stranded nucleic acid molecule comprising at least one G-U base pair, in an amount effective to stimulate TLR8 signaling.

85. A method for supplementing a TLR8-mediated immune response, comprising:
contacting TLR8 with an effective amount of a TLR8 ligand to induce a TLR8-mediated immune response; and
contacting a TLR other than TLR8 with an effective amount of a ligand for the TLR other than TLR8 to induce an immune response mediated by the TLR other than TLR8.

86. A method for supplementing a TLR8-mediated immune response in a subject, comprising:

administering to a subject in need of an immune response an effective amount of a TLR8 ligand to induce a TLR8-mediated immune response; and

administering to the subject an effective amount of a ligand for a TLR other than TLR8 to induce an immune response mediated by the TLR other than TLR8.

87. The method according to claim 86, wherein the TLR other than TLR8 is TLR9.

88. The method according to claim 87, wherein the ligand for TLR9 is a CpG nucleic acid.

89. The method according to claim 88, wherein the CpG nucleic acid has a stabilized backbone.

90. The method according to claim 87, wherein the ligand for TLR8 and the ligand for TLR9 are a conjugate.

91. The method according to claim 90, wherein the conjugate comprises a double-stranded DNA:RNA heteroduplex.

92. The method according to claim 90, wherein the conjugate comprises a chimeric DNA:RNA backbone.

93. The method according to claim 92, wherein the chimeric backbone comprises a cleavage site between the DNA and the RNA.

94. A method for stimulating TLR7 signaling, comprising:
contacting TLR7 with an isolated guanosine ribonucleoside in an effective amount to stimulate TLR7 signaling.

95. The method according to claim 94, wherein the guanosine ribonucleoside is a guanosine ribonucleoside derivative selected from the group consisting of: 8-bromoguanosine, 8-oxoguanosine, 8-mercaptoguanosine, 7-allyl-8-oxoguanosine, guanosine ribonucleoside vanadyl complex, inosine, and nebularine.

96. The method according to claim 95, wherein the guanosine ribonucleoside derivative is 8-oxoguanosine.

97. The method according to claim 94, wherein the guanosine nucleoside is a ribonucleoside.

98. The method according to claim 97, wherein the guanosine nucleoside comprises a mixture of ribonucleosides and deoxyribonucleosides.

99. A method for stimulating TLR7 signaling, comprising:
contacting TLR7 with an isolated nucleic acid comprising a terminal oxidized or halogenized guanosine in an effective amount to stimulate TLR7 signaling.

100. The method according to claim 99, wherein the oxidized or halogenized guanosine is 8-oxoguanosine

101. A method for stimulating TLR7 signaling, comprising:
contacting TLR7 with an isolated RNA in an effective amount to stimulate TLR7 signaling.

102. The method according to claim 101, wherein the RNA is double-stranded RNA.

103. The method according to claim 101, wherein the RNA is ribosomal RNA.

104. The method according to claim 101, wherein the RNA is transfer RNA.

105. The method according to claim 101, wherein the RNA is messenger RNA.

106. The method according to claim 101, wherein the RNA is viral RNA.

107. The method according to claim 101, wherein the RNA is G-rich RNA.

108. The method according to claim 107, further wherein the RNA is part of a DNA:RNA heteroduplex.

109. The method according to claim 107, wherein the RNA consists essentially of guanosine ribonucleoside.

110. A method for stimulating TLR7 signaling, comprising:
contacting TLR7 with a mixture of ribonucleoside vanadyl complexes.

111. The method according to claim 110, wherein the mixture comprises guanosine ribonucleoside vanadyl complexes.

112. A method for supplementing a TLR7-mediated immune response, comprising:
contacting TLR7 with an effective amount of a TLR7 ligand to induce a TLR7-mediated immune response; and
contacting a TLR other than TLR7 with an effective amount of a ligand for the TLR other than TLR7 to induce an immune response mediated by the TLR other than TLR7.

113. A method for supplementing a TLR7-mediated immune response in a subject, comprising:
administering to a subject in need of an immune response an effective amount of a TLR7 ligand to induce a TLR7-mediated immune response; and
administering to the subject an effective amount of a ligand for a TLR other than TLR7 to induce an immune response mediated by the TLR other than TLR7.

114. The method according to claim 113, wherein the TLR other than TLR7 is TLR9.

115. The method according to claim 114, wherein the ligand for TLR9 is a CpG nucleic acid.

116. The method according to claim 115, wherein the CpG nucleic acid has a stabilized backbone.

117. The method according to claim 114, wherein the ligand for TLR7 and the ligand for TLR9 are a conjugate.

118. The method according to claim 117, wherein the conjugate comprises a double-stranded DNA:RNA heteroduplex.

119. The method according to claim 117, wherein the conjugate comprises a chimeric DNA:RNA backbone.

120. The method according to claim 119, wherein the chimeric backbone comprises a cleavage site between the DNA and the RNA.

121. A method for screening candidate immunostimulatory compounds, comprising:

measuring a TLR8-mediated reference signal in response to an RNA reference;

measuring a TLR8-mediated test signal in response to a candidate immunostimulatory compound; and

comparing the TLR8-mediated test signal to the TLR8-mediated reference signal.

122. A method for screening candidate immunostimulatory compounds, comprising:

measuring a TLR8-mediated reference signal in response to an imidazoquinoline reference;

measuring a TLR8-mediated test signal in response to a candidate immunostimulatory compound; and

comparing the TLR8-mediated test signal to the TLR8-mediated reference signal.

123. The method according to claim 122, wherein the imidazoquinoline is resiquimod (R-848).

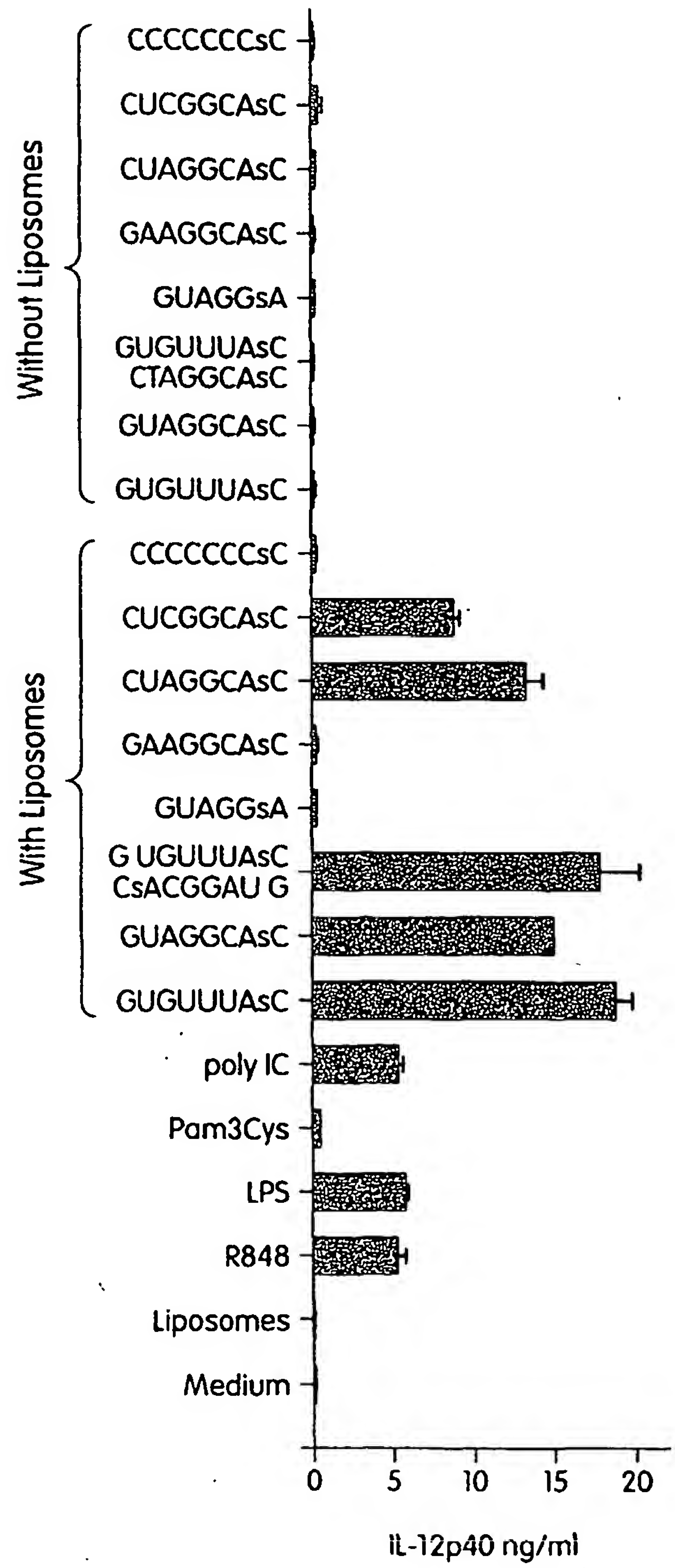
124. The method according to claim 122, wherein the imidazoquinoline is imiquimod (R-837).

125. A method for screening candidate immunostimulatory compounds, comprising:
measuring a TLR7-mediated reference signal in response to a 7-allyl-8-oxoguanosine reference;
measuring a TLR7-mediated test signal in response to a candidate immunostimulatory compound; and
comparing the TLR7-mediated test signal to the TLR7-mediated reference signal.

126. A method for screening candidate immunostimulatory compounds, comprising:
measuring a TLR7-mediated reference signal in response to an imidazoquinoline reference;
measuring a TLR7-mediated test signal in response to a candidate immunostimulatory compound; and
comparing the TLR7-mediated test signal to the TLR7-mediated reference signal.

127. The method according to claim 126, wherein the imidazoquinoline is resiquimod (R-848).

128. The method according to claim 126, wherein the imidazoquinoline is imiquimod (R-837).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With Liposomes
CCCCCCCsC
CUCGGCAsC
CUAGGCAsC
GAAGGCAsC
GUAGGsA
G UGUUUAsC
CsACGGAU G
GUAGGCAsC
GUGUUUAsC
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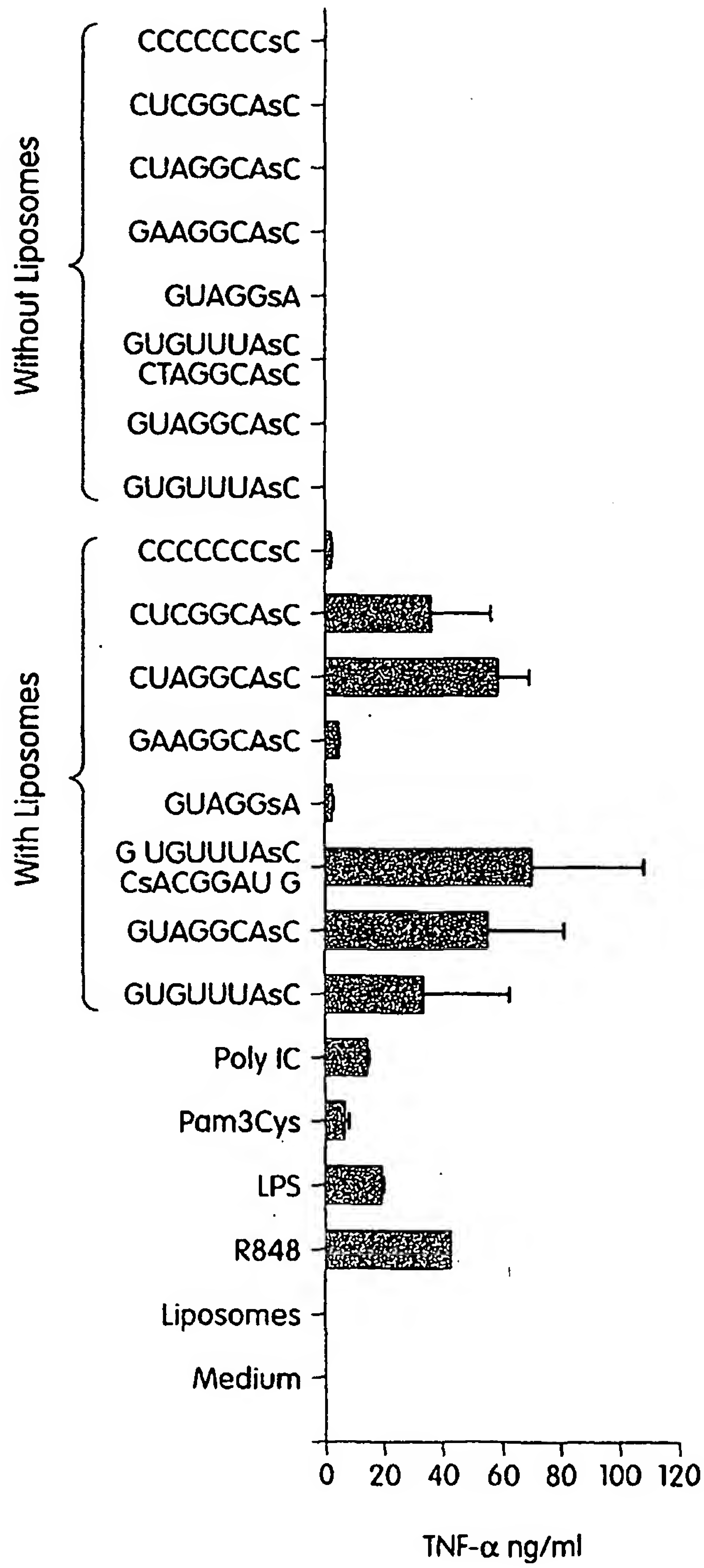
Pam3Cys
LPS
R848
Liposomes
Medium
0
5
10
15
20
IL-12p40 ng/ml

Fig. 1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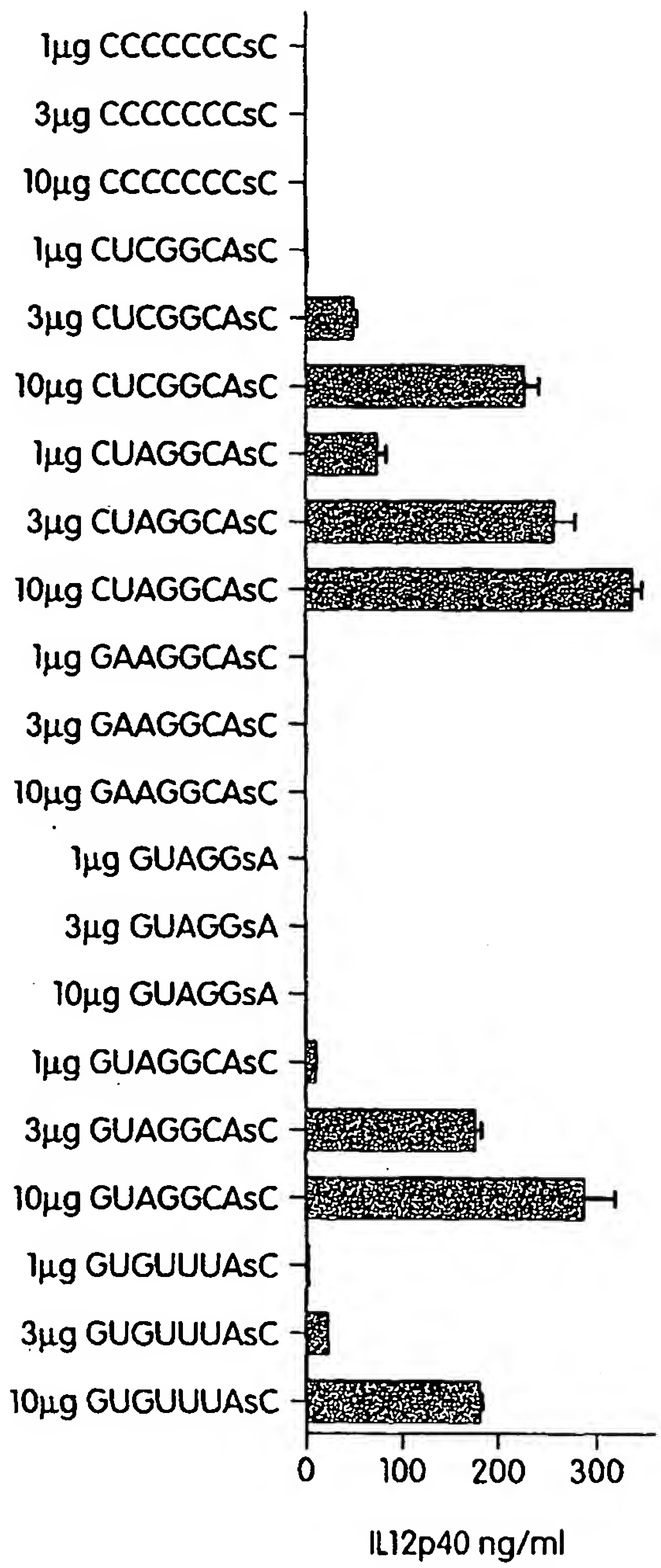
With Liposomes
CCCCCCCsC
CUCGGCAsC
CUAGGCAsC
GAAGGCAsC
GUAGGsA
G UGUUUAsC
CsACGGAU G
GUAGGCAsC
GUGUUUAsC
Poly IC
Pam3Cys
LPS
R848
Liposomes
Medium
0 20 40 60 80 100 120
TNF-α ng/ml

Fig. 2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10µg CCCCCCCsC
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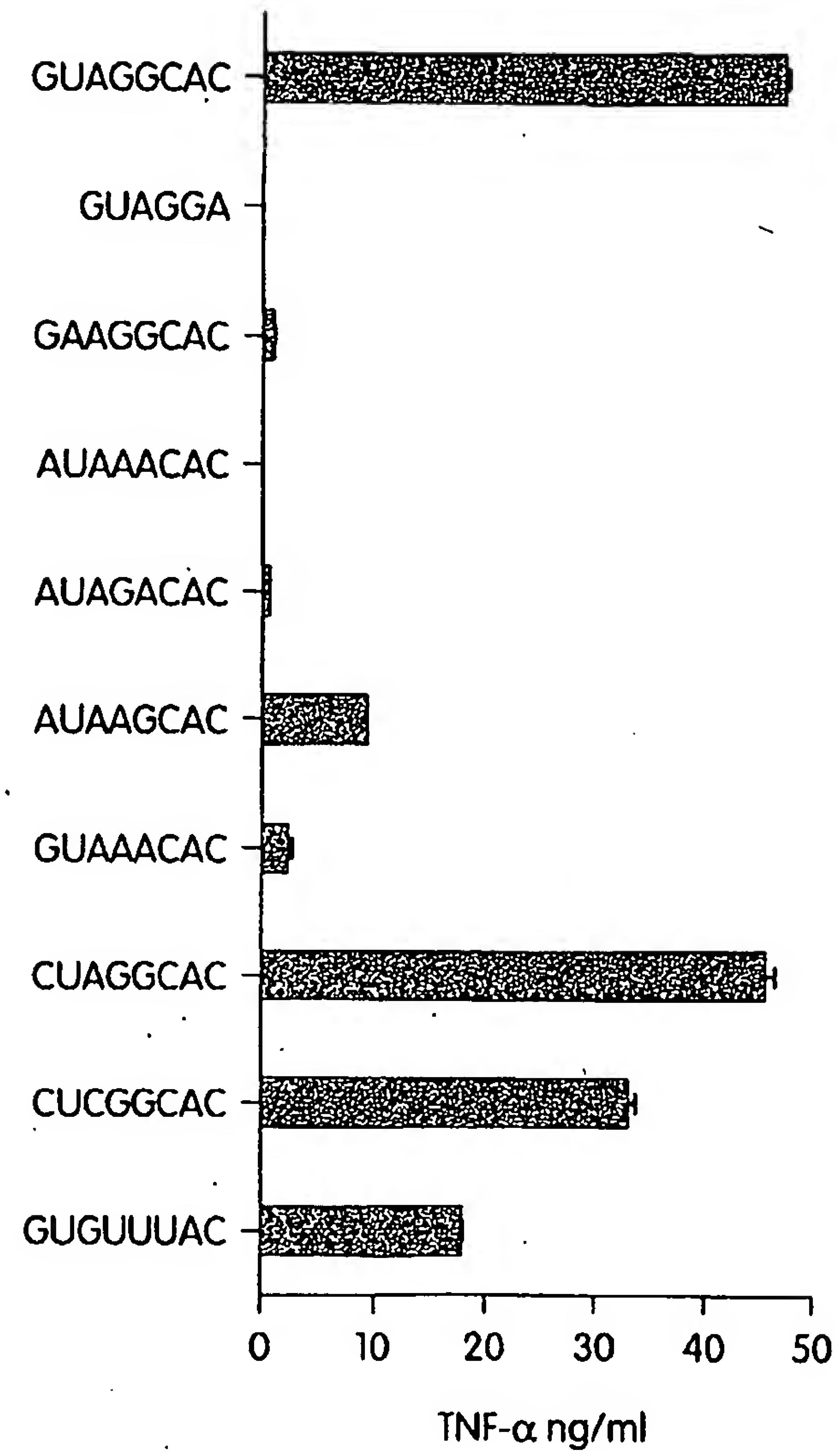
3µg CUAGGCAsC
10µg CUAGGCAsC
1µg GAAGGCAsC
3µg GAAGGCAsC
10µg GAAGGCAsC
1µg GUAGGsA
3µg GUAGGsA
10µg GUAGGsA
1µg GUAGGCAsC
3µg GUAGGCAsC
10µg GUAGGCAsC
1µg GUGUUUAsC
3µg GUGUUUAsC
10µg GUGUUUAsC
0
100
200
300
IL12p40 ng/ml

Fig. 3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AUAGACAC
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GUGUUUAC
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10
20
30
40
50
TNF-α ng/ml

Fig. 4

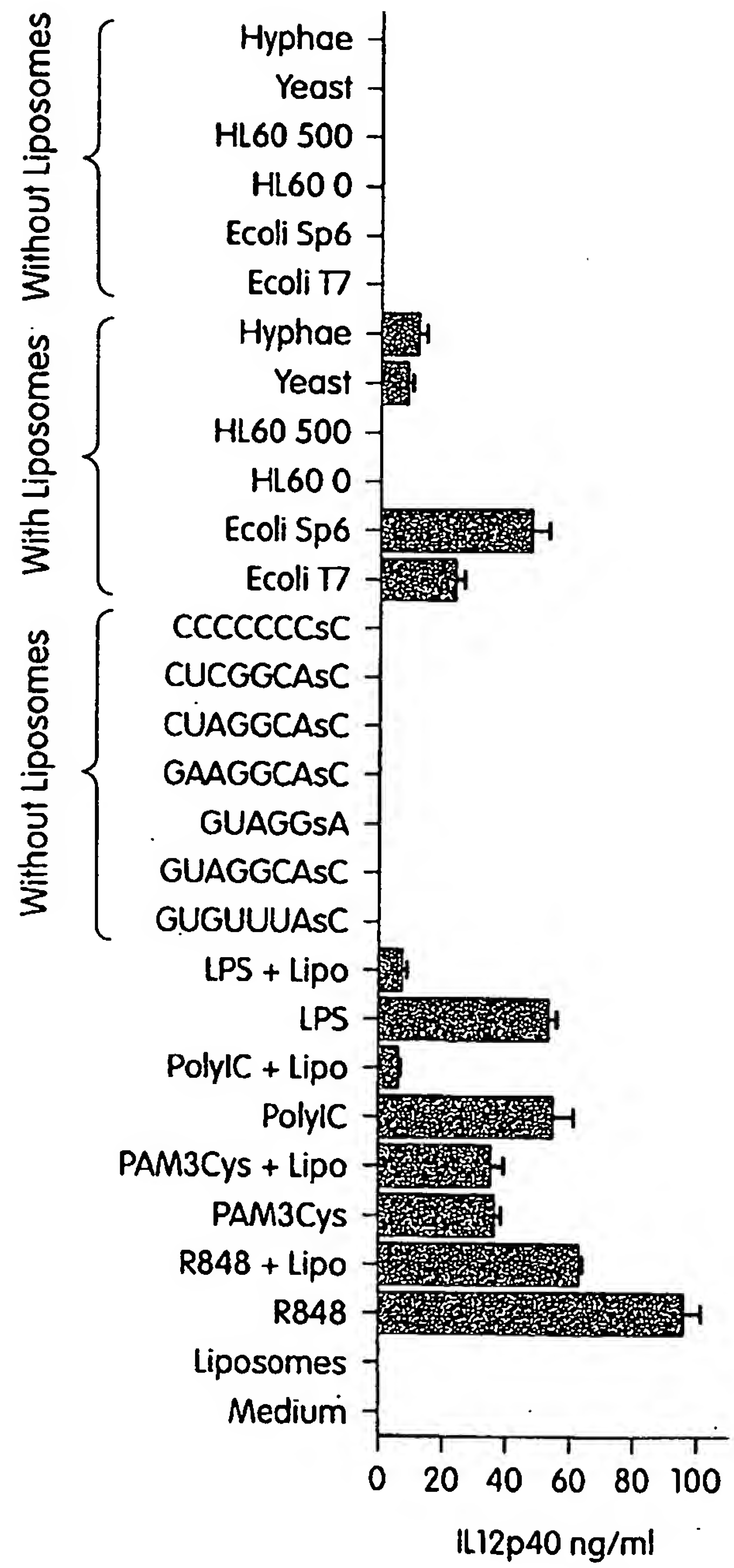

Without Liposomes
Hyphae
Yeast
HL60 500
HL60 0
Ecoli Sp6
Ecoli T7
With Liposomes
Hyphae
Yeast
HL60 500
HL60 0
Ecoli Sp6
Ecoli T7
Without Liposomes
CCCCCCCsC
CUCGGCAsC
CUAGGCAsC
GAAGGCAsC
GUAGGsA
GUAGGCAsC
GUGUUUAsC
LPS + Lipo
LPS
PolyIC + Lipo
PolyIC
PAM3Cys + Lipo
PAM3Cys
R848 + Lipo
R848
Liposomes
Medium
0
20
40
60
80
100
IL12p40 ng/ml

Fig. 5

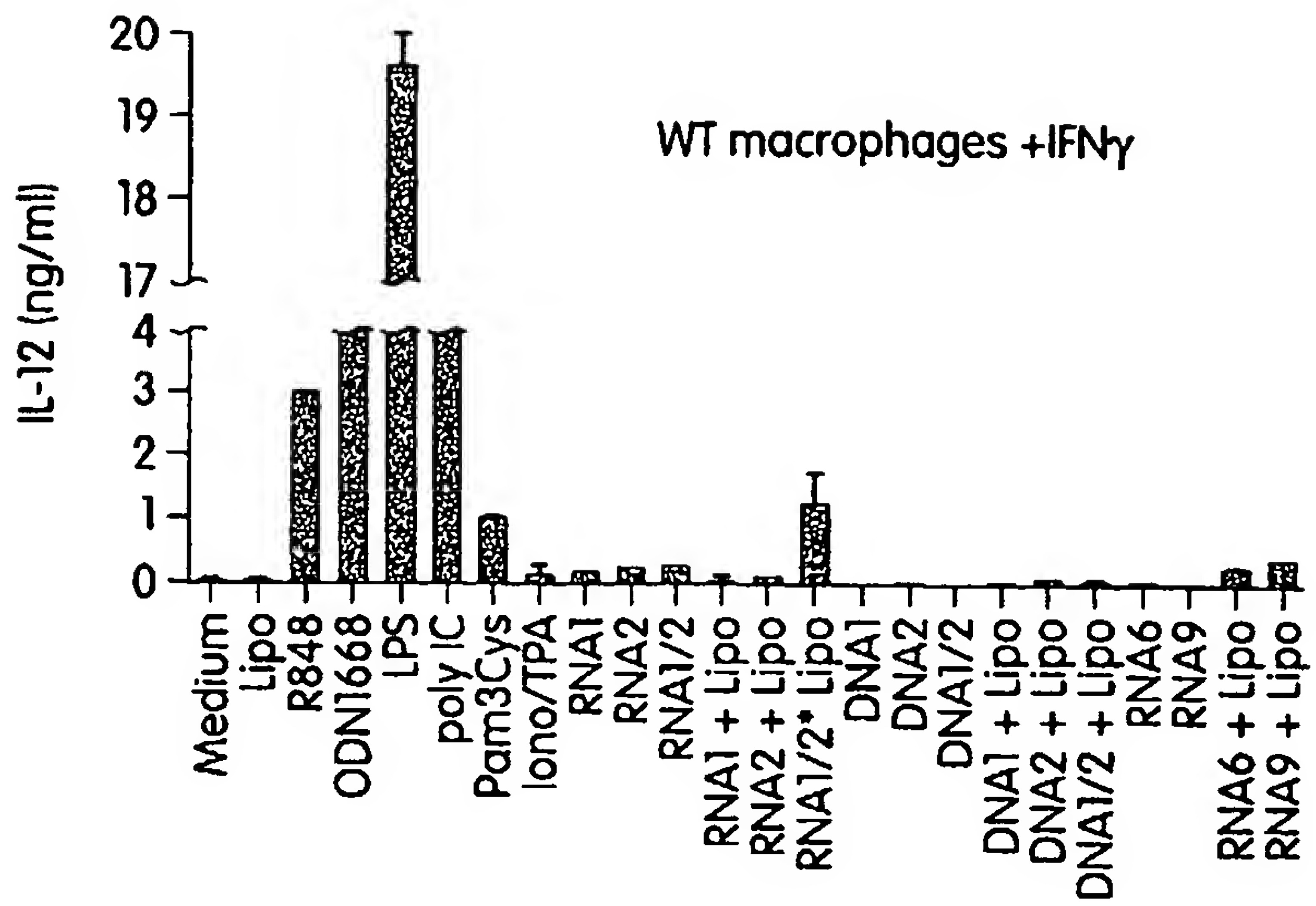
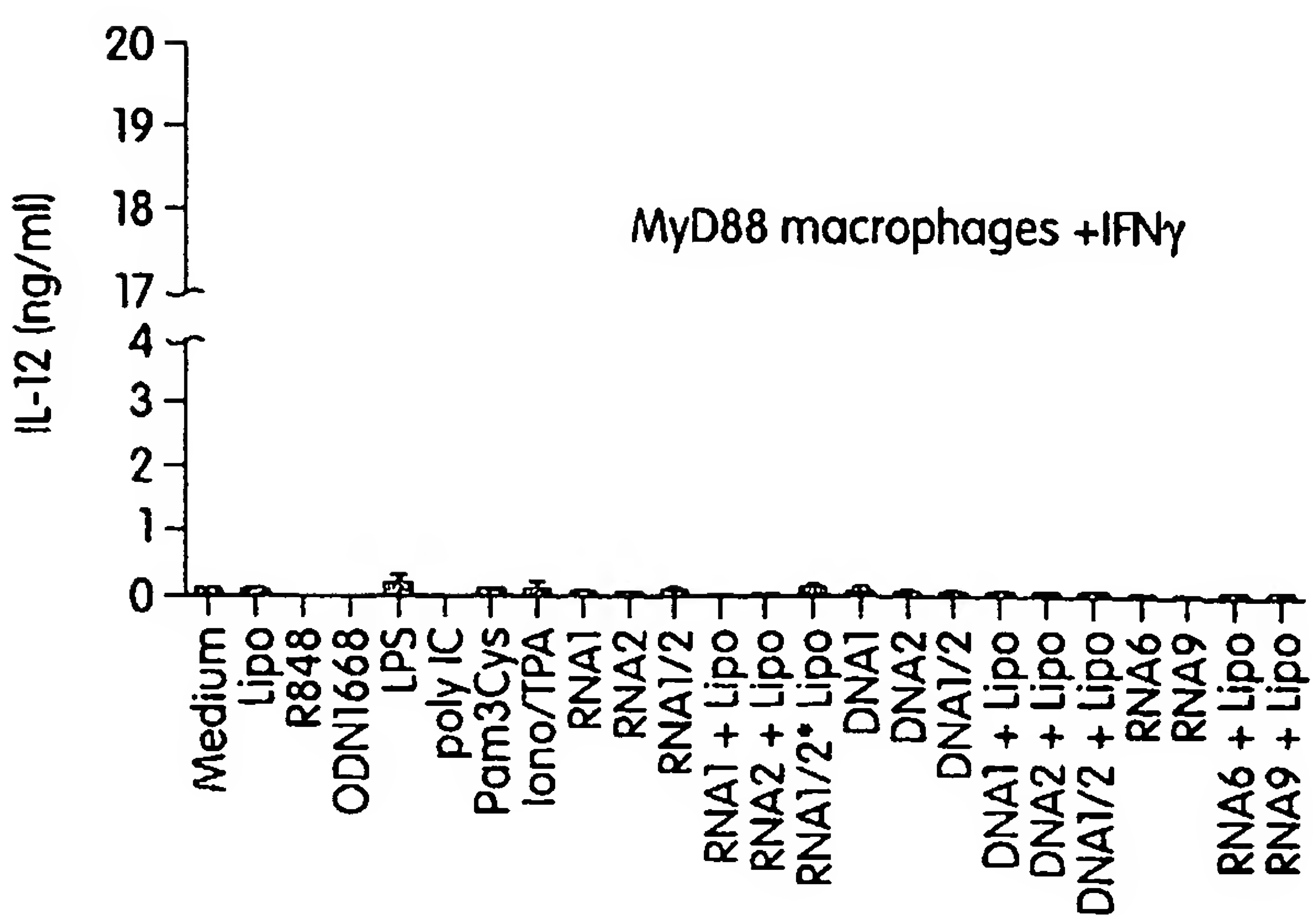

WT macrophages +IFNγ
IL-12 (ng/ml)
20
19
18
17
4
3
2
1
0
Medium
Lipo
R848
ODN1668
LPS
poly IC
Pam3Cys
Iono/TPA
RNA1
RNA2
RNA1/2
RNA1 + Lipo
RNA2 + Lipo
RNA1/2* Lipo
DNA1
DNA2
DNA1/2
DNA1 + Lipo
DNA2 + Lipo
DNA1/2 + Lipo
RNA6
RNA9
RNA6 + Lipo
RNA9 + Lipo

Fig. 6A


MyD88 macrophages +IFNγ
IL-12 (ng/ml)
20
19
18
17
4
3
2
1
0
Medium
Lipo
R848
ODN1668
LPS
poly IC
Pam3Cys
Iono/TPA
RNA1
RNA2
RNA1/2
RNA1 + Lipo
RNA2 + Lipo
RNA1/2* Lipo
DNA1
DNA2
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DNA2 + Lipo
DNA1/2 + Lipo
RNA6
RNA9
RNA6 + Lipo
RNA9 + Lipo

Fig. 6B

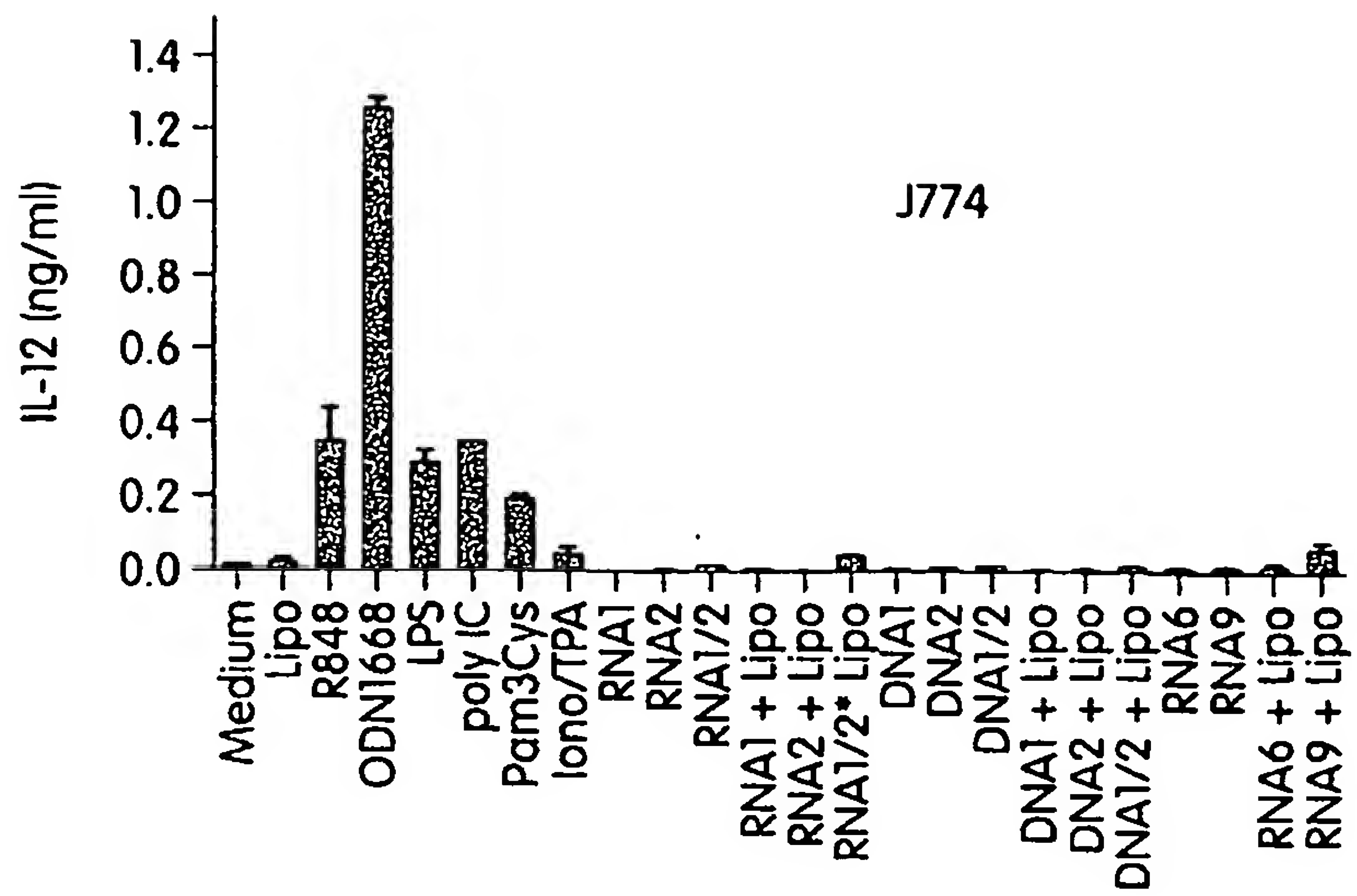
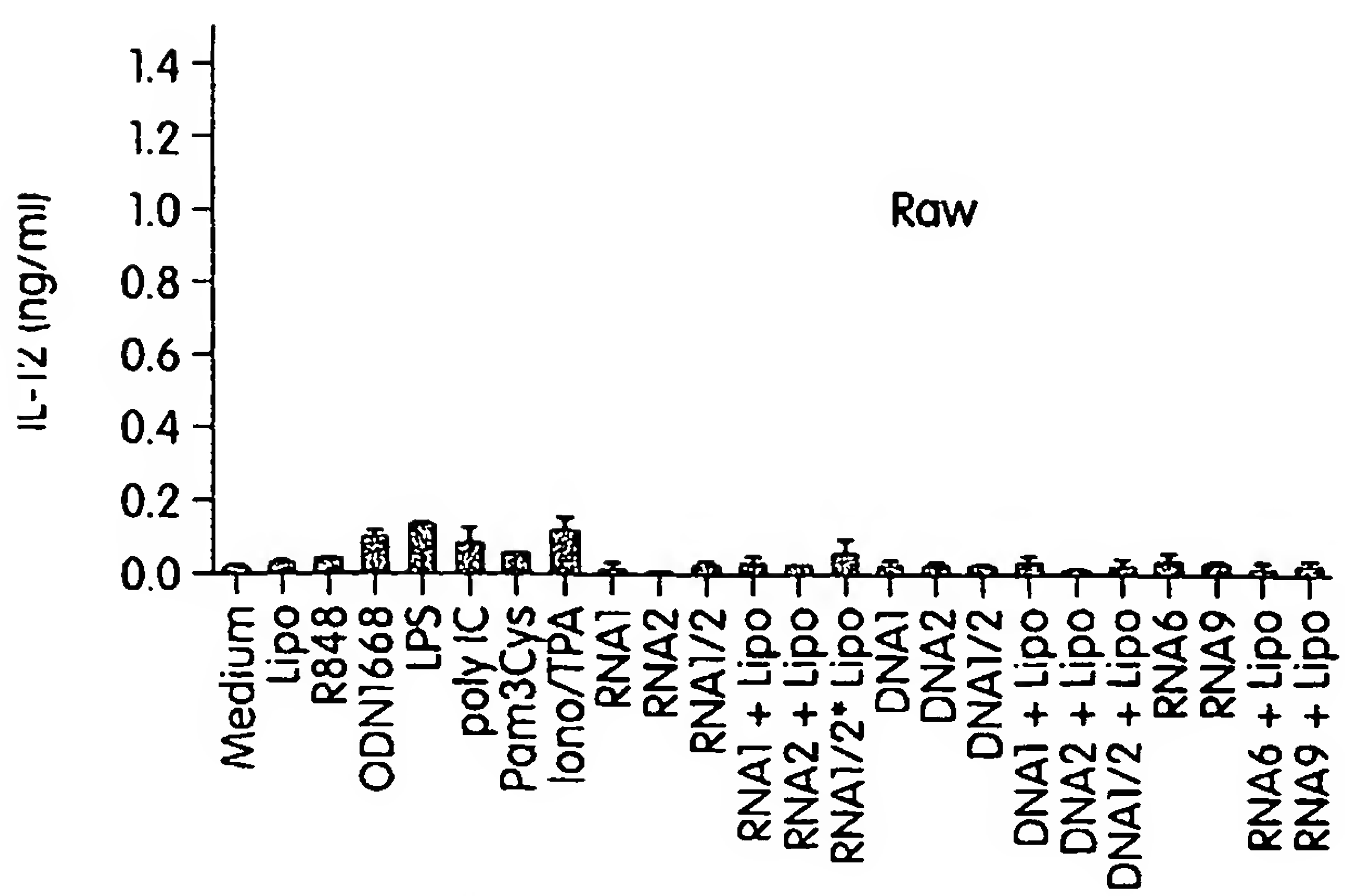

IL-12 (ng/ml)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
J774
Medium
Lipo
R848
ODN1668
LPS
poly IC
Pam3Cys
Iono/TPA
RNA1
RNA2
RNA1/2
RNA1 + Lipo
RNA2 + Lipo
RNA1/2* Lipo
DNA1
DNA2
DNA1/2
DNA1 + Lipo
DNA2 + Lipo
DNA1/2 + Lipo
RNA6
RNA9
RNA6 + Lipo
RNA9 + Lipo

Fig. 6C


IL-12 (ng/ml)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Raw
Medium
Lipo
R848
ODN1668
LPS
poly IC
Pam3Cys
Iono/TPA
RNA1
RNA2
RNA1/2
RNA1 + Lipo
RNA2 + Lipo
RNA1/2* Lipo
DNA1
DNA2
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DNA2 + Lipo
DNA1/2 + Lipo
RNA6
RNA9
RNA6 + Lipo
RNA9 + Lipo

Fig. 6D

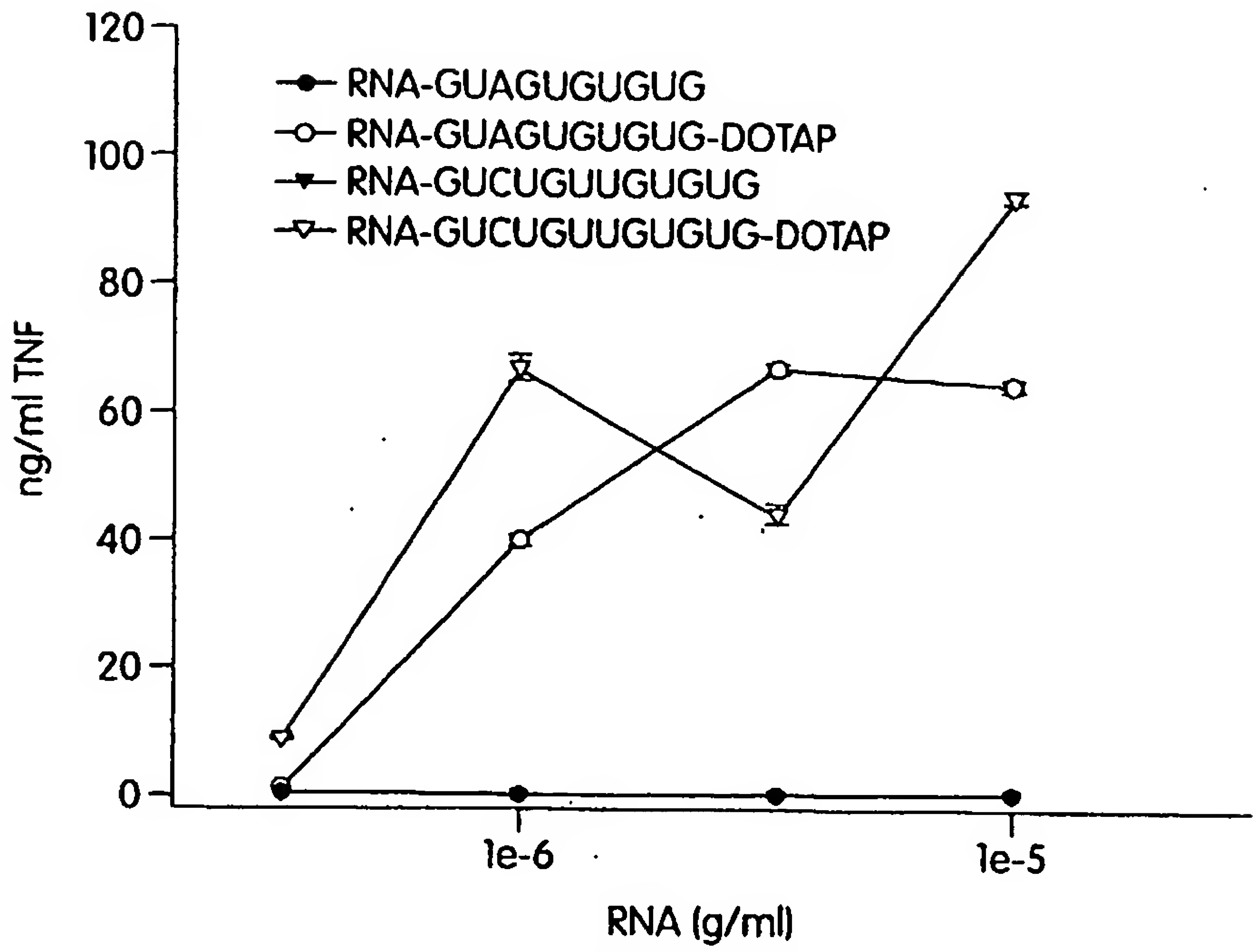

120
100
80
60
40
20
0
ng/ml TNF
RNA-GUAGUGUGUG
RNA-GUAGUGUGUG-DOTAP
RNA-GUCUGUUGUGUG
RNA-GUCUGUUGUGUG-DOTAP
1e-6
1e-5
RNA (g/ml)

Fig. 7A

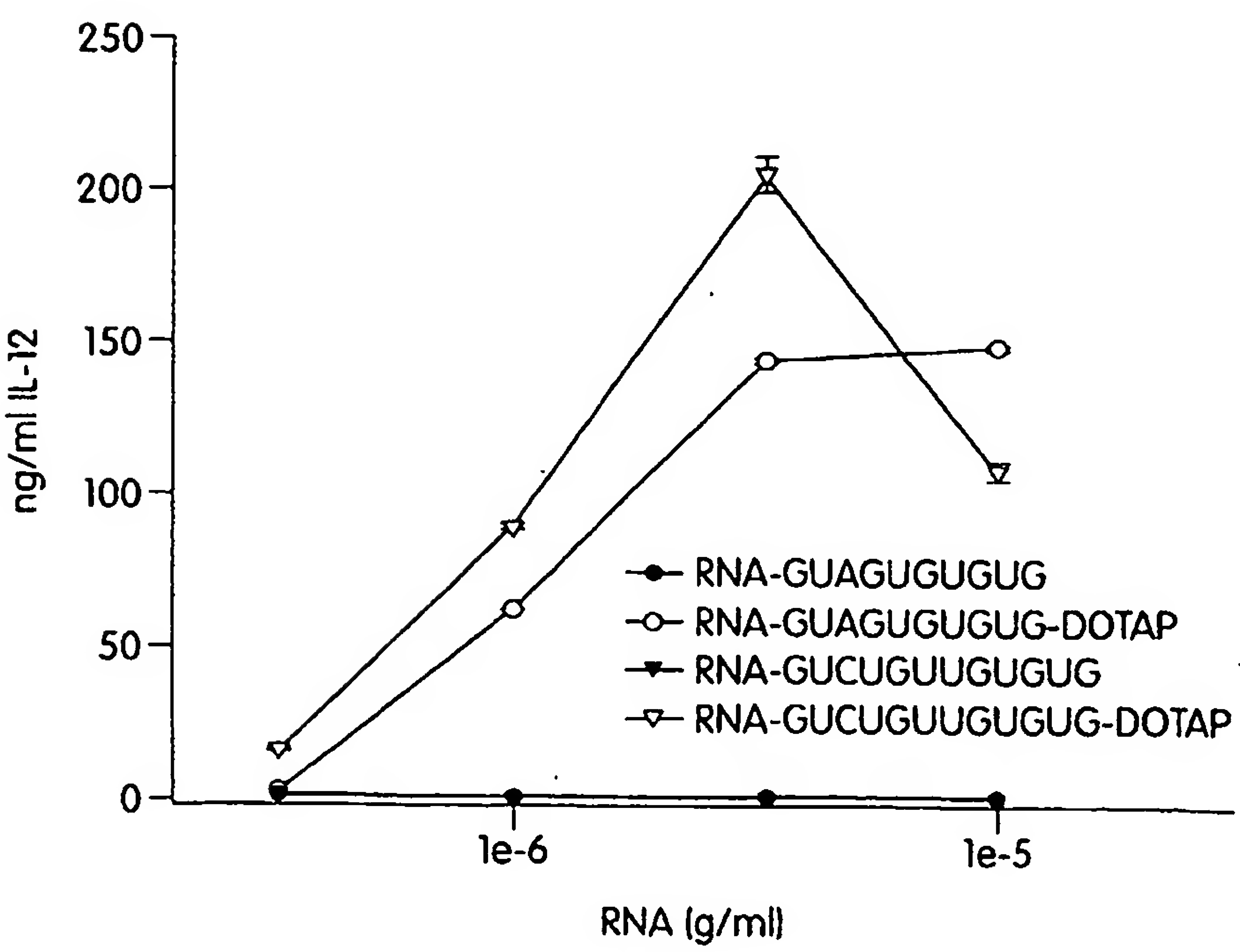

250
200
150
100
50
0
ng/ml IL-12
RNA-GUAGUGUGUG
RNA-GUAGUGUGUG-DOTAP
RNA-GUCUGUUGUGUG
RNA-GUCUGUUGUGUG-DOTAP
1e-6
1e-5
RNA (g/ml)

Fig. 7B

HOMOLOGY AMONG TOLL-LIKE RECEPTORS

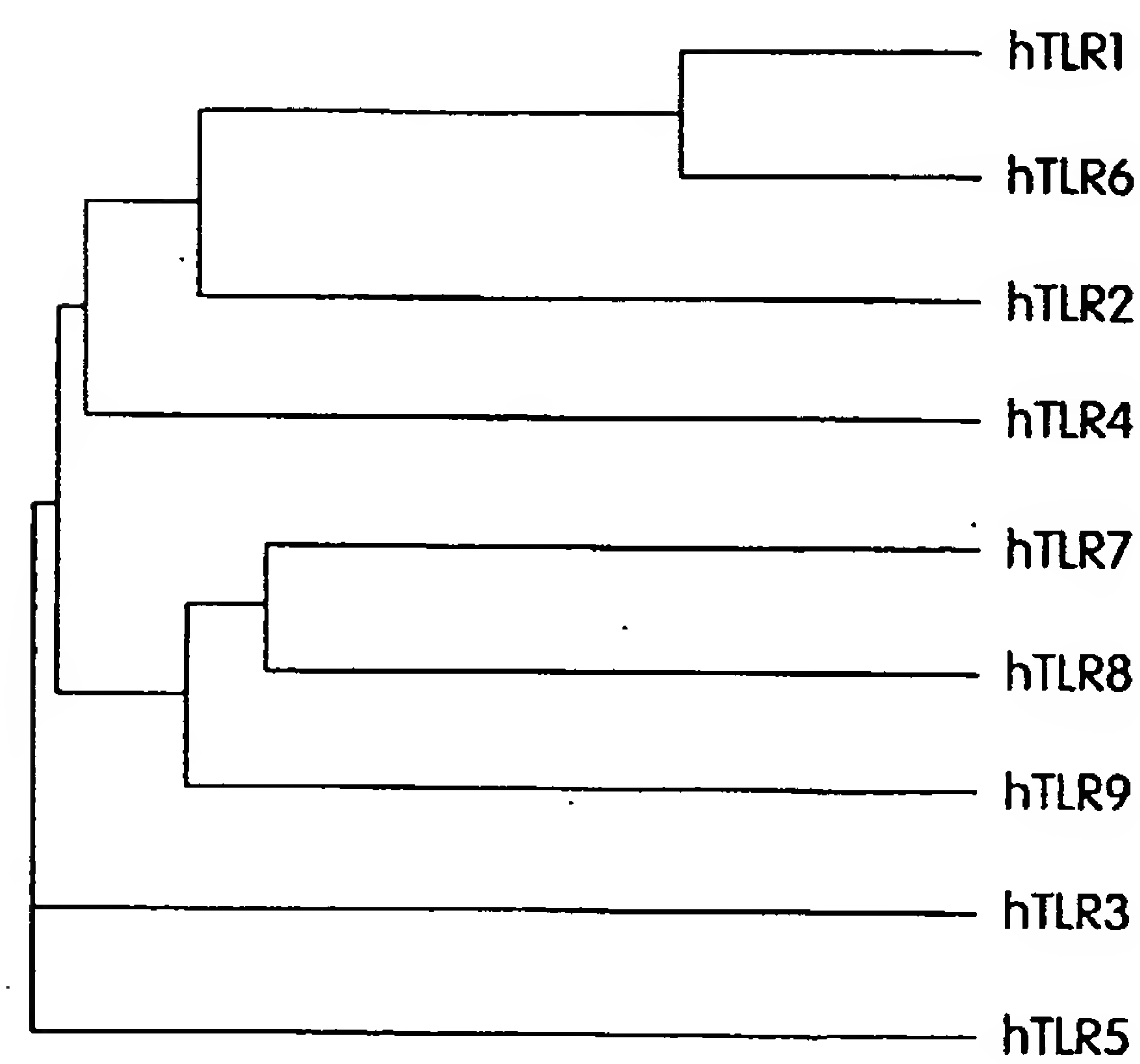


Fig. 8

TLR7 AND TLR8 HAVE TLR9-LIKE NUCLEIC ACID BINDING DOMAINS

CXXC motif	GNCXXCXXXXXXXCXXC
Human TLR9	GNCRRCDHAPNPCMEC
Murine TLR9	GNCRRCDHAPNPCMIC
Human TLR8	GNCPRCFNAPFPCVPC
Human TLR7	GNCPRCYNAPFPCAPC

MBD motif

```
           *      *    *    *   *           * *
MBD-1  V-X-R-XXXX-T-XX-R-X-D-X-Y-XXXXXXXXX-R-S
hTLR9  G-X-Q-XXXX-S-XX-K-X-D-X-Y-XXXXXXXXX-R-L
hTLR8  H-X-K-XXXX-T-XX-R-X-D-X-D-XXXXXXXXX-D-L
hTLR7  E-X-R-XXXX-S-XX-R-X-D-X-L-XXXXXXXXX-K-L
```

Fig. 9

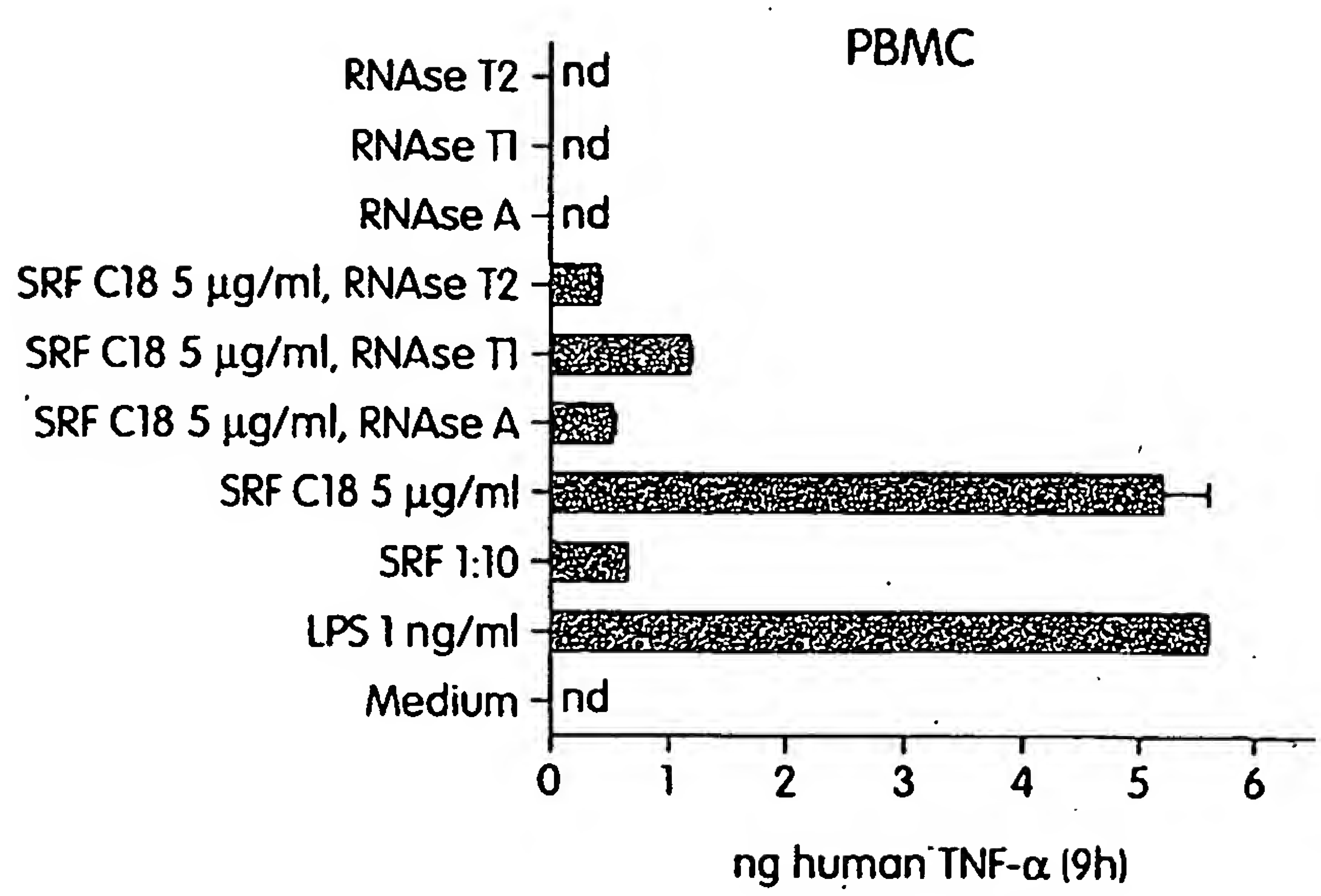

PBMC
RNAse T2
RNAse T1
RNAse A
SRF C18 5 µg/ml, RNAse T2
SRF C18 5 µg/ml, RNAse T1
SRF C18 5 µg/ml, RNAse A
SRF C18 5 µg/ml
SRF 1:10
LPS 1 ng/ml
Medium
nd
0
1
2
3
4
5
6
ng human TNF-α (9h)

Fig. 10

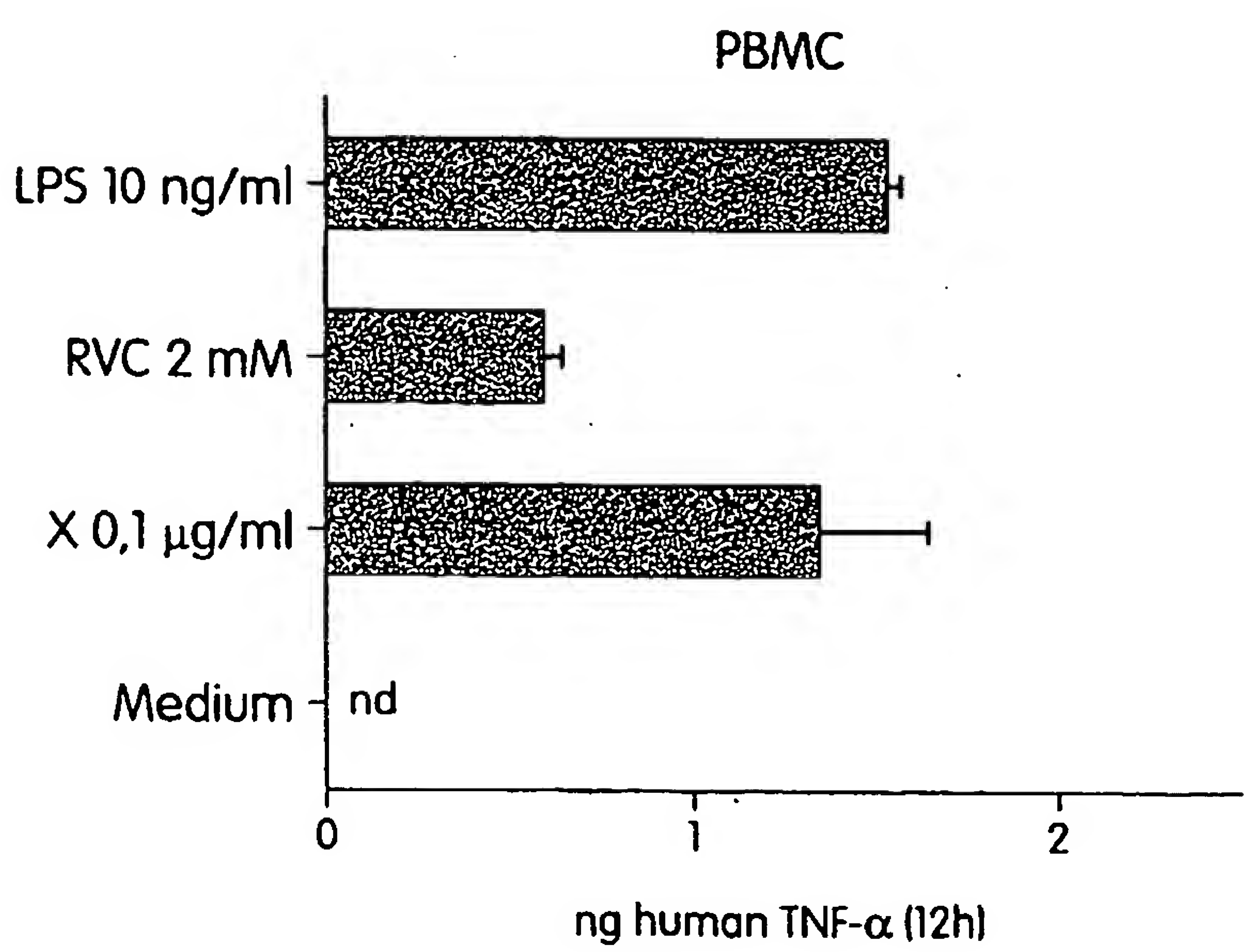
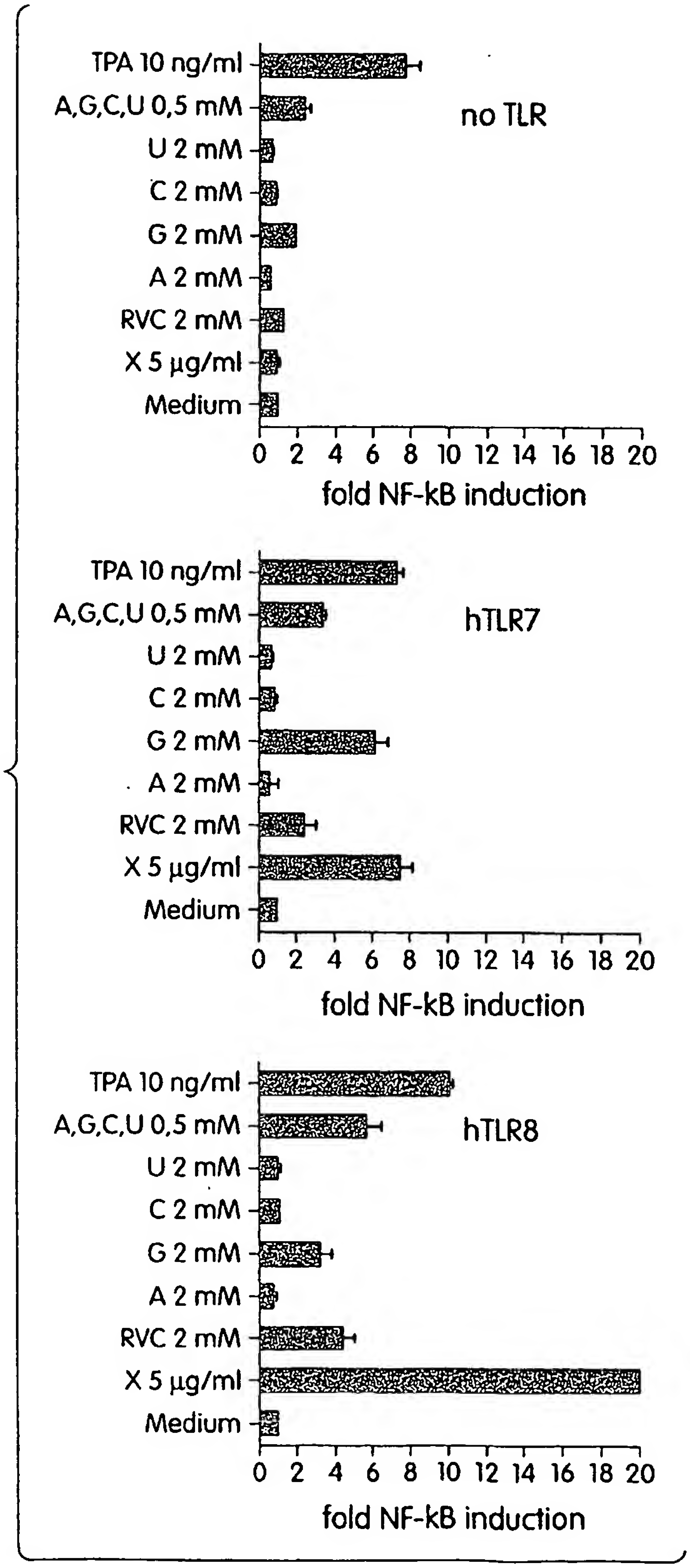

PBMC
LPS 10 ng/ml
RVC 2 mM
X 0,1 µg/ml
Medium
nd
0
1
2
ng human TNF-α (12h)

Fig. 11

Fig. 12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A,G,C,U 0,5 mM
U 2 mM
C 2 mM
G 2 mM
A 2 mM
RVC 2 mM
X 5 µg/ml
Medium
no TLR
0 2 4 6 8 10 12 14 16 18 20
fold NF-kB induction
TPA 10 ng/ml
A,G,C,U 0,5 mM
U 2 mM
C 2 mM
G 2 mM
A 2 mM
RVC 2 mM
X 5 µg/ml
Medium
hTLR7
0 2 4 6 8 10 12 14 16 18 20
fold NF-kB induction
TPA 10 ng/ml
A,G,C,U 0,5 mM
U 2 mM
C 2 mM
G 2 mM
A 2 mM
RVC 2 mM
X 5 µg/ml
Medium
hTLR8
0 2 4 6 8 10 12 14 16 18 20
fold NF-kB induction

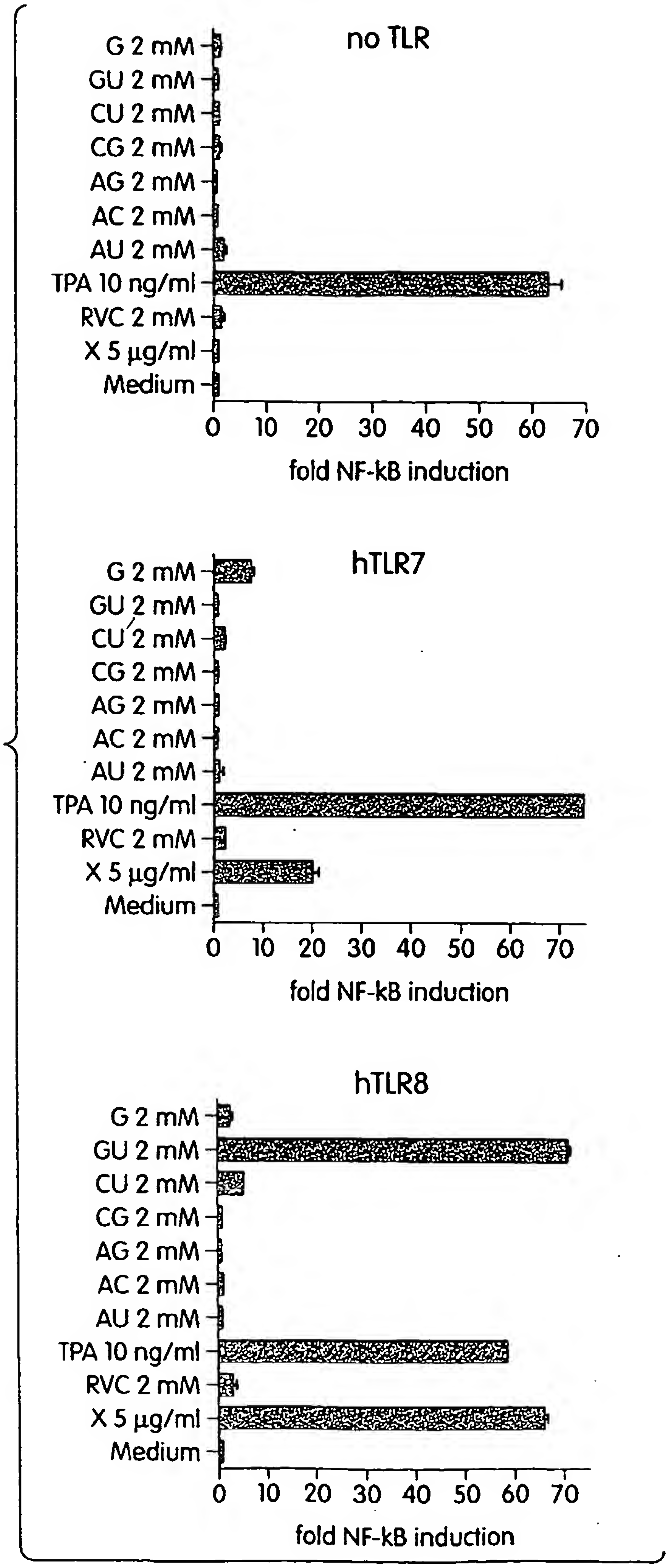

no TLR
G 2 mM
GU 2 mM
CU 2 mM
CG 2 mM
AG 2 mM
AC 2 mM
AU 2 mM
TPA 10 ng/ml
RVC 2 mM
X 5 µg/ml
Medium
0 10 20 30 40 50 60 70
fold NF-kB induction
hTLR7
G 2 mM
GU 2 mM
CU 2 mM
CG 2 mM
AG 2 mM
AC 2 mM
AU 2 mM
TPA 10 ng/ml
RVC 2 mM
X 5 µg/ml
Medium
0 10 20 30 40 50 60 70
fold NF-kB induction
hTLR8
G 2 mM
GU 2 mM
CU 2 mM
CG 2 mM
AG 2 mM
AC 2 mM
AU 2 mM
TPA 10 ng/ml
RVC 2 mM
X 5 µg/ml
Medium
0 10 20 30 40 50 60 70
fold NF-kB induction

Fig. 13

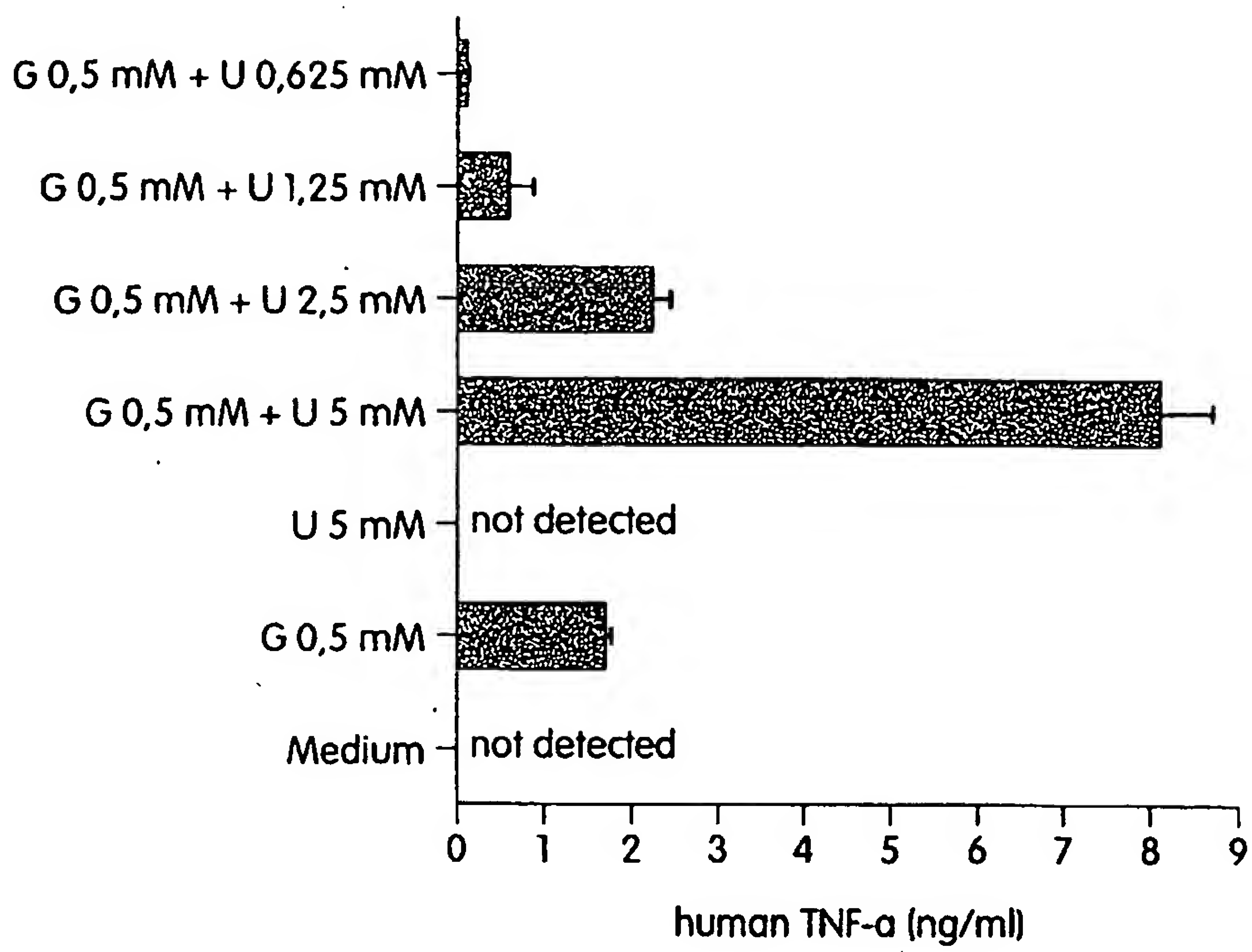

G 0,5 mM + U 0,625 mM
G 0,5 mM + U 1,25 mM
G 0,5 mM + U 2,5 mM
G 0,5 mM + U 5 mM
U 5 mM
not detected
G 0,5 mM
Medium
not detected
0
1
2
3
4
5
6
7
8
9
human TNF-a (ng/ml)

Fig. 14

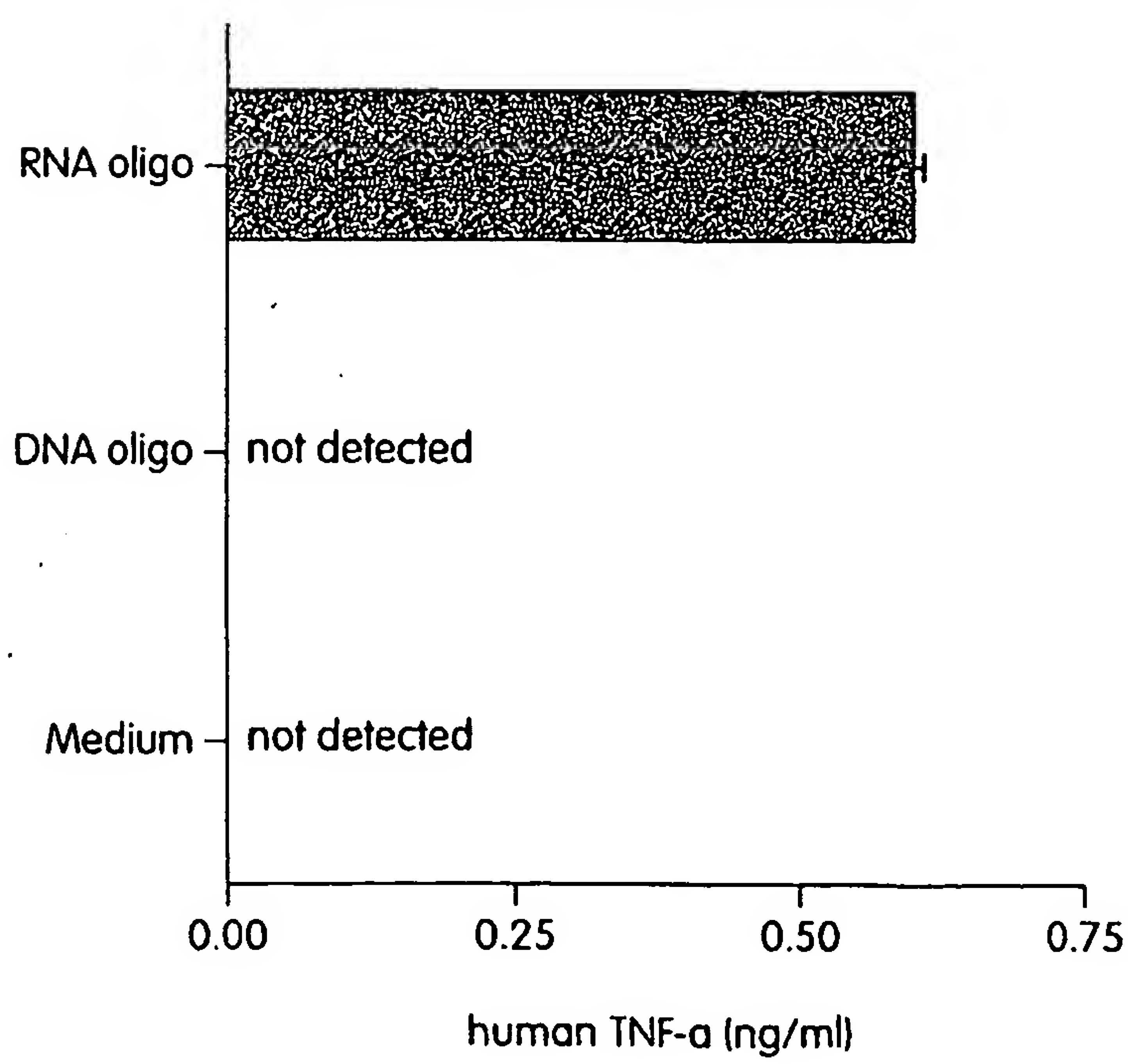
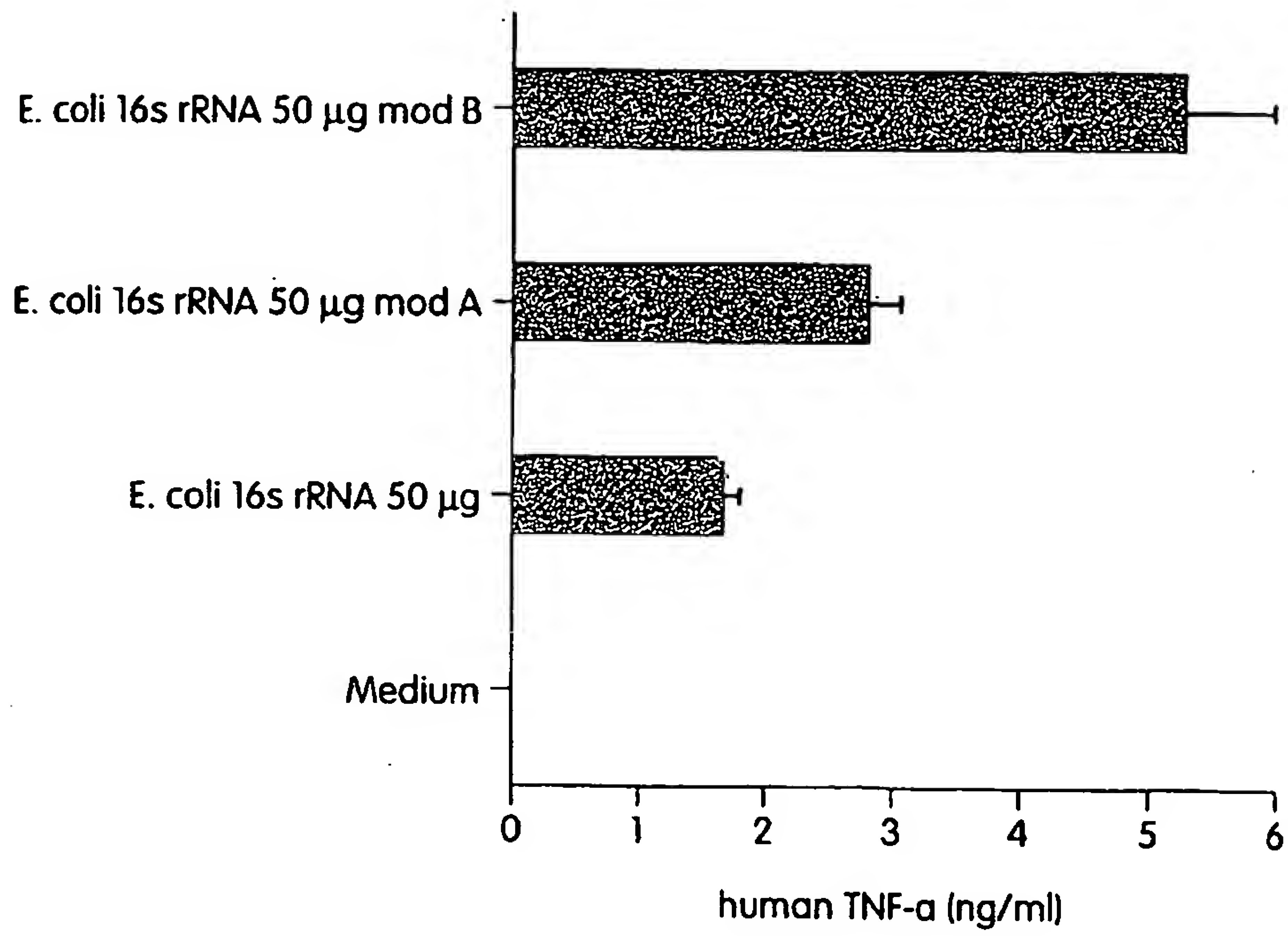

RNA oligo
DNA oligo
not detected
Medium
not detected
0.00
0.25
0.50
0.75
human TNF-a (ng/ml)

Fig. 15



E. coli 16s rRNA 50 µg mod B
E. coli 16s rRNA 50 µg mod A
E. coli 16s rRNA 50 µg
Medium
0
1
2
3
4
5
6
human TNF-α (ng/ml)

Fig. 16

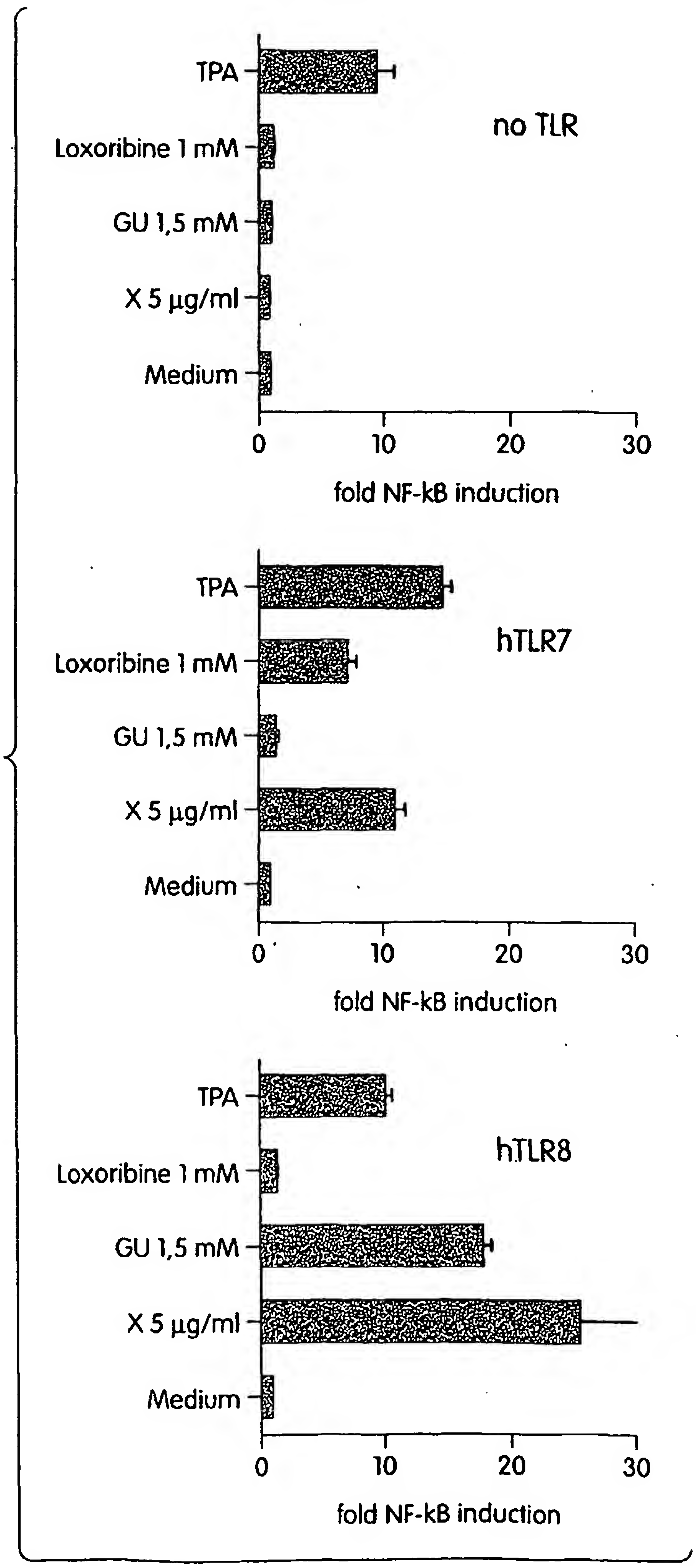
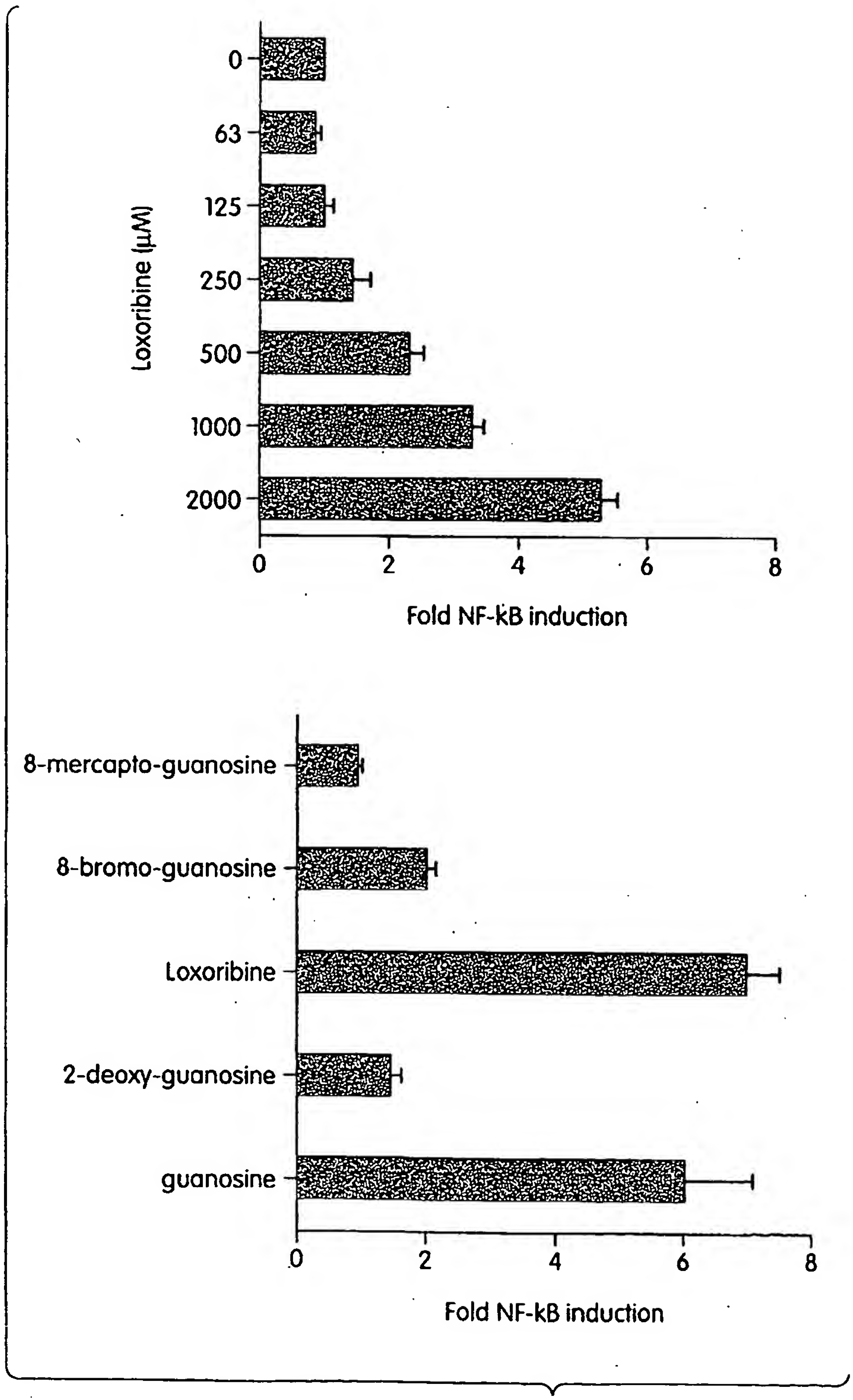

TPA
Loxoribine 1 mM
GU 1,5 mM
X 5 µg/ml
Medium
no TLR
0
10
20
30
fold NF-kB induction
TPA
Loxoribine 1 mM
GU 1,5 mM
X 5 µg/ml
Medium
hTLR7
0
10
20
30
fold NF-kB induction
TPA
Loxoribine 1 mM
GU 1,5 mM
X 5 µg/ml
Medium
hTLR8
0
10
20
30
fold NF-kB induction

Fig. 17



0
63
125
250
500
1000
2000
Loxoribine (µM)
0
2
4
6
8
Fold NF-kB induction
8-mercapto-guanosine
8-bromo-guanosine
Loxoribine
2-deoxy-guanosine
guanosine
0
2
4
6
8
Fold NF-kB induction

Fig. 18

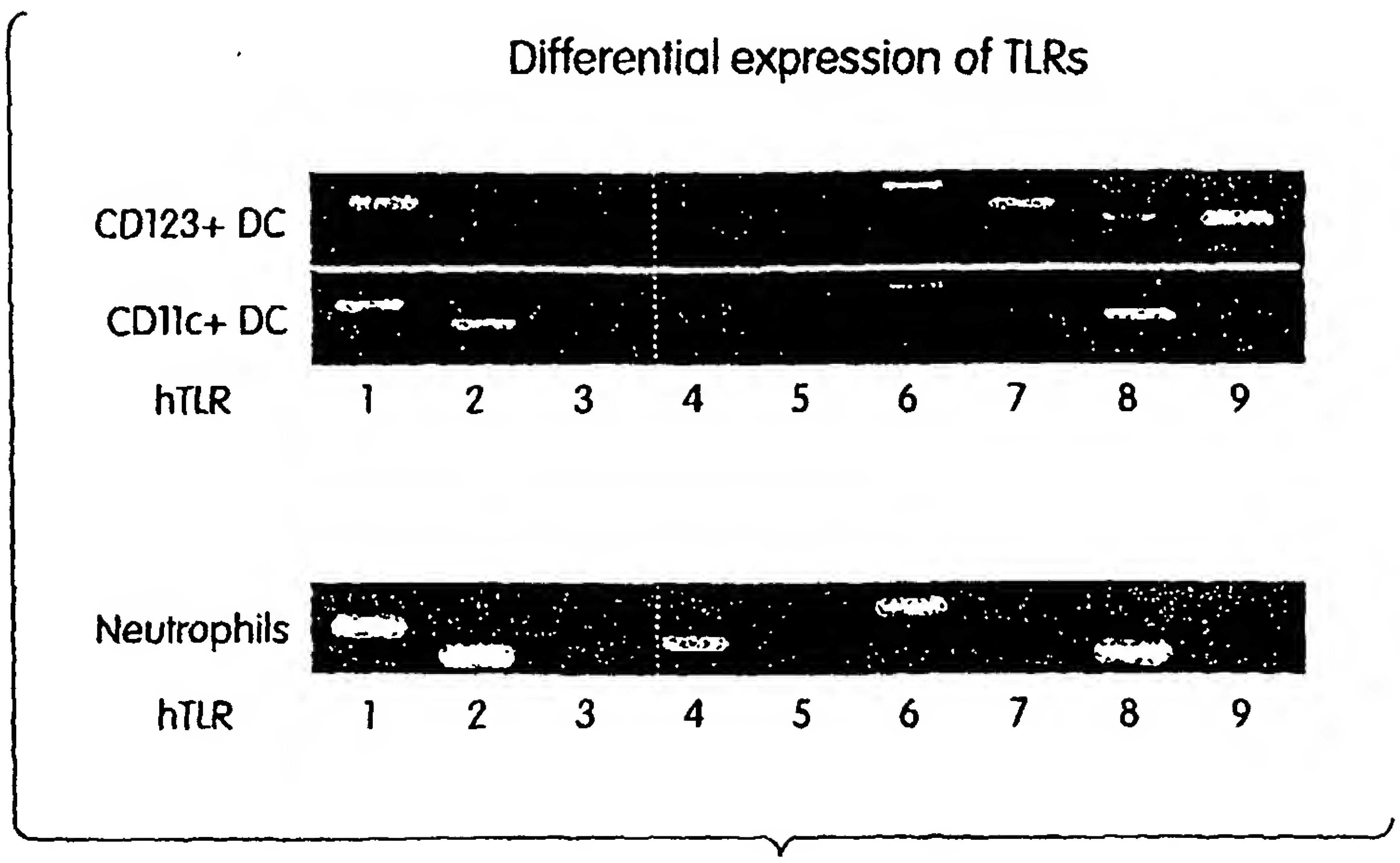
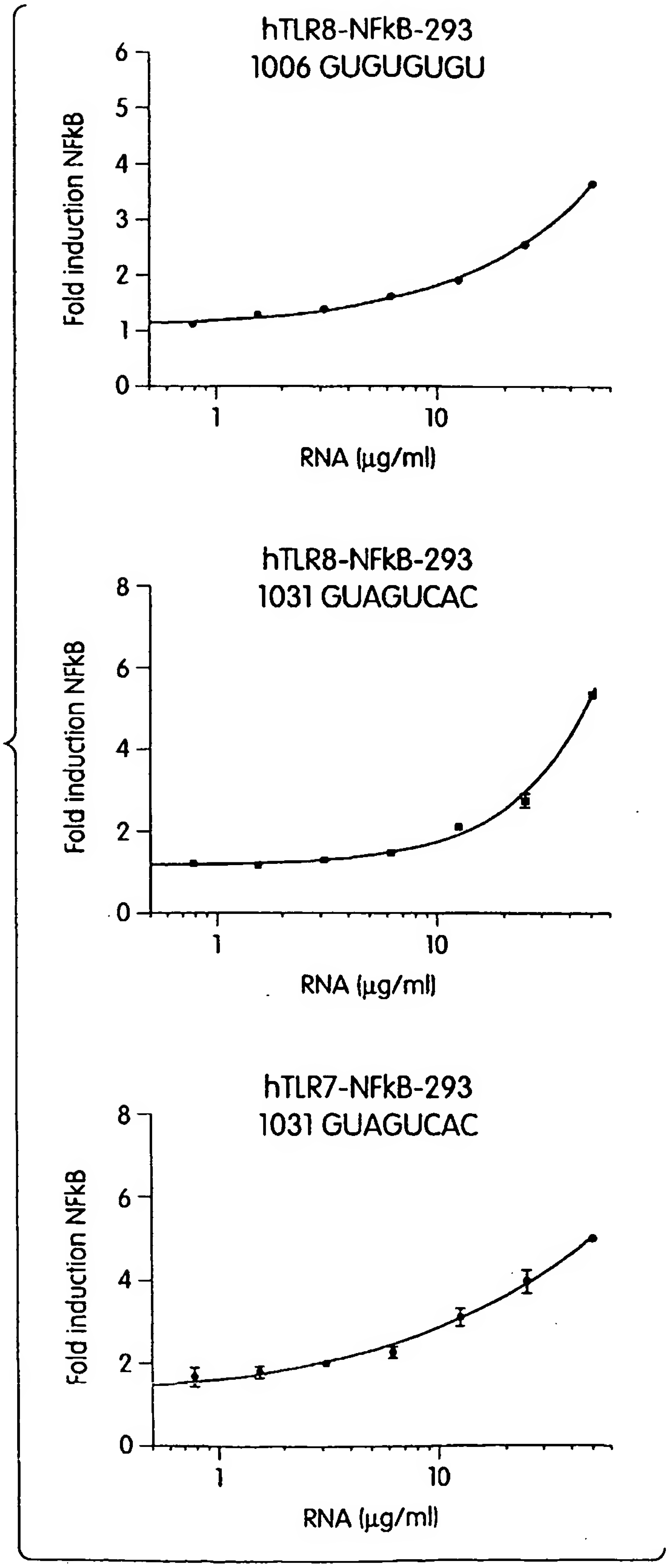

Differential expression of TLRs
CD123+ DC
CD11c+ DC
hTLR
1 2 3 4 5 6 7 8 9
Neutrophils
hTLR
1 2 3 4 5 6 7 8 9

Fig. 19

Fig. 20


hTLR8-NFkB-293
1006 GUGUGUGU
Fold induction NFkB
6
5
4
3
2
1
0
1
10
RNA (µg/ml)
hTLR8-NFkB-293
1031 GUAGUCAC
Fold induction NFkB
8
6
4
2
0
1
10
RNA (µg/ml)
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Fold induction NFkB
8
6
4
2
0
1
10
RNA (µg/ml)

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20 25 30

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35 40 45

Leu Pro Thr Asn Ile Thr Val Leu Asn Leu Thr His Asn Gln Leu Arg
50 55 60

Arg Leu Pro Ala Ala Asn Phe Thr Arg Tyr Ser Gln Leu Thr Ser Leu
65 70 75 80

Asp Val Gly Phe Asn Thr Ile Ser Lys Leu Glu Pro Glu Leu Cys Gln
85 90 95

Lys Leu Pro Met Leu Lys Val Leu Asn Leu Gln His Asn Glu Leu Ser
100 105 110

Gln Leu Ser Asp Lys Thr Phe Ala Phe Cys Thr Asn Leu Thr Glu Leu
115 120 125

His Leu Met Ser Asn Ser Ile Gln Lys Ile Lys Asn Asn Pro Phe Val
130 135 140

Lys Gln Lys Asn Leu Ile Thr Leu Asp Leu Ser His Asn Gly Leu Ser
145 150 155 160

Ser Thr Lys Leu Gly Thr Gln Val Gln Leu Glu Asn Leu Gln Glu Leu
165 170 175

Leu Leu Ser Asn Asn Lys Ile Gln Ala Leu Lys Ser Glu Glu Leu Asp
180 185 190

Ile Phe Ala Asn Ser Ser Leu Lys Lys Leu Glu Leu Ser Ser Asn Gln
195 200 205

Ile Lys Glu Phe Ser Pro Gly Cys Phe His Ala Ile Gly Arg Leu Phe

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Gly Leu Phe Leu Asn Asn Val Gln Leu Gly Pro Ser Leu Thr Glu Lys
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Leu Cys Leu Glu Leu Ala Asn Thr Ser Ile Arg Asn Leu Ser Leu Ser
245 250 255

Asn Ser Gln Leu Ser Thr Thr Ser Asn Thr Thr Phe Leu Gly Leu Lys
260 265 270

Trp Thr Asn Leu Thr Met Leu Asp Leu Ser Tyr Asn Asn Leu Asn Val
275 280 285

Val Gly Asn Asp Ser Phe Ala Trp Leu Pro Gln Leu Glu Tyr Phe Phe
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Leu Glu Tyr Asn Asn Ile Gln His Leu Phe Ser His Ser Leu His Gly
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Leu Phe Asn Val Arg Tyr Leu Asn Leu Lys Arg Ser Phe Thr Lys Gln
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340 345 350

Trp Leu Lys Cys Leu Glu His Leu Asn Met Glu Asp Asn Asp Ile Pro
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Gly Ile Lys Ser Asn Met Phe Thr Gly Leu Ile Asn Leu Lys Tyr Leu
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Ser Leu Ser Asn Ser Phe Thr Ser Leu Arg Thr Leu Thr Asn Glu Thr
385 390 395 400

Phe Val Ser Leu Ala His Ser Pro Leu His Ile Leu Asn Leu Thr Lys
405 410 415

Asn Lys Ile Ser Lys Ile Glu Ser Asp Ala Phe Ser Trp Leu Gly His
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Leu Glu Val Leu Asp Leu Gly Leu Asn Glu Ile Gly Gln Glu Leu Thr
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Gly Gln Glu Trp Arg Gly Leu Glu Asn Ile Phe Glu Ile Tyr Leu Ser
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Ser Leu Gln Arg Leu Met Leu Arg Arg Val Ala Leu Lys Asn Val Asp
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Leu Ser Asn Asn Asn Ile Ala Asn Ile Asn Asp Asp Met Leu Glu Gly
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Gln Val Ser Leu Lys Ser Leu Asn Leu Gln Lys Asn Leu Ile Thr Ser
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Gln Phe Glu Tyr Ala Ala Tyr Ile Ile His Ala Tyr Lys Asp Lys Asp
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Cys Leu Arg Arg Gly Met Phe Lys Ser His Cys Ile Leu Asn Trp Pro
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Tyr Asn Val Ala Asp Cys Ser His Leu Lys Leu Thr His Ile Pro Asp
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Asp Leu Pro Ser Asn Ile Thr Val Leu Asn Leu Thr His Asn Gln Leu
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Arg Arg Leu Pro Pro Thr Asn Phe Thr Arg Tyr Ser Gln Leu Ala Ile
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Leu Asp Ala Gly Phe Asn Ser Ile Ser Lys Leu Glu Pro Glu Leu Cys
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Gln Ile Leu Pro Leu Leu Lys Val Leu Asn Leu Gln His Asn Glu Leu
            100                 105                 110

Ser Gln Ile Ser Asp Gln Thr Phe Val Phe Cys Thr Asn Leu Thr Glu
        115                 120                 125

Leu Asp Leu Met Ser Asn Ser Ile His Lys Ile Lys Ser Asn Pro Phe
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Lys Asn Gln Lys Asn Leu Ile Lys Leu Asp Leu Ser His Asn Gly Leu
145                 150                 155                 160

Ser Ser Thr Lys Leu Gly Thr Gly Val Gln Leu Glu Asn Leu Gln Glu
                165                 170                 175

Leu Leu Leu Ala Lys Asn Lys Ile Leu Ala Leu Arg Ser Glu Glu Leu
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Glu Phe Leu Gly Asn Ser Ser Leu Arg Lys Leu Asp Leu Ser Ser Asn
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Pro Leu Lys Glu Phe Ser Pro Gly Cys Phe Gln Thr Ile Gly Lys Leu
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Phe Ala Leu Leu Leu Asn Asn Ala Gln Leu Asn Pro His Leu Thr Glu
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Lys Leu Cys Trp Glu Leu Ser Asn Thr Ser Ile Gln Asn Leu Ser Leu
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Lys Trp Thr Asn Leu Thr Gln Leu Asp Leu Ser Tyr Asn Asn Leu His
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Ser Leu Glu Tyr Asn Asn Ile Gln Arg Leu Ser Pro Arg Ser Phe Tyr
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Gly Leu Ser Asn Leu Arg Tyr Leu Ser Leu Lys Arg Ala Phe Thr Lys
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Gln Ser Val Ser Leu Ala Ser His Pro Asn Ile Asp Asp Phe Ser Phe
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Gln Trp Leu Lys Tyr Leu Glu Tyr Leu Asn Met Asp Asp Asn Asn Ile
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Pro Ser Thr Lys Ser Asn Thr Phe Thr Gly Leu Val Ser Leu Lys Tyr
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Leu Ser Leu Ser Lys Thr Phe Thr Ser Leu Gln Thr Leu Thr Asn Glu
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Thr Phe Val Ser Leu Ala His Ser Pro Leu Leu Thr Leu Asn Leu Thr
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Lys Asn His Ile Ser Lys Ile Ala Asn Gly Thr Phe Ser Trp Leu Gly
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Gln Leu Arg Ile Leu Asp Leu Gly Leu Asn Glu Ile Glu Gln Lys Leu
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Ser Gly Gln Glu Trp Arg Gly Leu Arg Asn Ile Phe Glu Ile Tyr Leu
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Ser Tyr Asn Lys Tyr Leu Gln Leu Ser Thr Ser Ser Phe Ala Leu Val
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Pro Ser Leu Gln Arg Leu Met Leu Arg Arg Val Ala Leu Lys Asn Val
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Asp Ile Ser Pro Ser Pro Phe Arg Pro Leu Arg Asn Leu Thr Ile Leu
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Glu Ile Pro Val Gly Val Phe Lys Asn Leu Phe Glu Leu Lys Ser Ile
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Asn Leu Gly Leu Asn Asn Leu Asn Lys Leu Glu Pro Phe Ile Phe Asp
595 600 605

Asp Gln Thr Ser Leu Arg Ser Leu Asn Leu Gln Lys Asn Leu Ile Thr
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Ser Val Glu Lys Asp Val Phe Gly Pro Pro Phe Gln Asn Leu Asn Ser
625 630 635 640

Leu Asp Met Arg Phe Asn Pro Phe Asp Cys Thr Cys Glu Ser Ile Ser
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Trp Phe Val Asn Trp Ile Asn Gln Thr His Thr Asn Ile Phe Glu Leu
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Ser Thr His Tyr Leu Cys Asn Thr Pro His His Tyr Tyr Gly Phe Pro
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Leu Lys Leu Phe Asp Thr Ser Ser Cys Lys Asp Ser Ala Pro Phe Glu
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Val Leu Leu Ile His Ile Glu Gly Trp Arg Ile Ser Phe Tyr Trp Asn
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Val Ser Val His Arg Ile Leu Gly Phe Lys Glu Ile Asp Thr Gln Ala
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Glu Gln Phe Glu Tyr Thr Ala Tyr Ile Ile His Ala His Lys Asp Arg
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Asp Trp Val Trp Glu His Phe Ser Pro Met Glu Glu Gln Asp Gln Ser
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Leu Glu Ala Ile Val Asn Ser Ile Lys Arg Ser Arg Lys Ile Ile Phe
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Val His His Ala Val Gln Gln Ala Ile Glu Gln Asn Leu Asp Ser Ile
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Val Asp Cys Thr Asp Lys His Leu Thr Glu Ile Pro Gly Gly Ile Pro
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Ser Pro Ala Ser Phe His Arg Leu Asp His Leu Val Glu Ile Asp Phe
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Arg Cys Asn Cys Val Pro Ile Pro Leu Gly Ser Lys Asn Asn Met Cys
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Ile Lys Arg Leu Gln Ile Lys Pro Arg Ser Phe Ser Gly Leu Thr Tyr
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Leu Lys Ser Leu Tyr Leu Asp Gly Asn Gln Leu Leu Glu Ile Pro Gln
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Phe Ser Ile Arg Lys Glu Asn Leu Thr Glu Leu Ala Asn Ile Glu Ile
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Leu Tyr Leu Gly Gln Asn Cys Tyr Tyr Arg Asn Pro Cys Tyr Val Ser
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Tyr Ser Ile Glu Lys Asp Ala Phe Leu Asn Leu Thr Lys Leu Lys Val
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Gln Glu Asp Asp Phe Asn Asn Leu Asn Gln Leu Gln Ile Leu Asp Leu
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Ser Gly Asn Cys Pro Arg Cys Tyr Asn Ala Pro Phe Pro Cys Ala Pro
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Cys Lys Asn Asn Ser Pro Leu Gln Ile Pro Val Asn Ala Phe Asp Ala
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His Phe Leu Pro Ser Leu Ile Gln Leu Asp Leu Ser Phe Asn Phe Glu
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Leu Lys Ser Leu Lys Ile Leu Arg Ile Arg Gly Tyr Val Phe Lys Glu
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Ala Phe Glu Glu Leu His Lys Leu Glu Val Leu Asp Ile Ser Ser Asn
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Ser His Tyr Phe Gln Ser Glu Gly Ile Thr His Met Leu Asn Phe Thr
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Lys Asn Leu Lys Val Leu Gln Lys Leu Met Met Asn Asp Asn Asp Ile
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Glu Phe Arg Gly Asn His Leu Asp Val Leu Trp Arg Glu Gly Asp Asn
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Arg Tyr Leu Gln Leu Phe Lys Asn Leu Leu Lys Leu Glu Glu Leu Asp
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Ile Ser Lys Asn Ser Leu Ser Phe Leu Pro Ser Gly Val Phe Asp Gly
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Met Pro Pro Asn Leu Lys Asn Leu Ser Leu Ala Lys Asn Gly Leu Lys
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Ser Phe Ser Trp Lys Lys Leu Gln Cys Leu Lys Asn Leu Glu Thr Leu
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Asp Leu Ser His Asn Gln Leu Thr Thr Val Pro Glu Arg Leu Ser Asn
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Cys Ser Arg Ser Leu Lys Asn Leu Ile Leu Lys Asn Asn Gln Ile Arg
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Ser Leu Thr Lys Tyr Phe Leu Gln Asp Ala Phe Gln Leu Arg Tyr Leu
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Phe Leu Cys Thr Cys Asp Ala Val Trp Phe Val Trp Trp Val Asn His
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Thr Glu Val Thr Ile Pro Tyr Leu Ala Thr Asp Val Thr Cys Val Gly
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Pro Gly Ala His Lys Gly Gln Ser Val Ile Ser Leu Asp Leu Tyr Thr
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Cys Glu Leu Asp Leu Thr Asn Leu Ile Leu Phe Ser Leu Ser Ile Ser
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Val Ser Leu Phe Leu Met Val Met Met Thr Ala Ser His Leu Tyr Phe
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Trp Asp Val Trp Tyr Ile Tyr His Phe Cys Lys Ala Lys Ile Lys Gly
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Arg Leu Met Asp Glu Lys Val Asp Val Ile Ile Leu Ile Phe Leu Glu

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Lys Pro Phe Gln Lys Ser Lys Phe Leu Gln Leu Arg Lys Arg Leu Cys
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Gly Ser Ser Val Leu Glu Trp Pro Thr Asn Pro Gln Ala His Pro
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Thr Leu Pro Cys Glu Val Lys Val Asn Ile Pro Glu Ala His Val Ile
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Val Asp Cys Thr Asp Lys His Leu Thr Glu Ile Pro Glu Gly Ile Pro
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Thr Asn Thr Thr Asn Leu Thr Leu Thr Ile Asn His Ile Pro Ser Ile
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Ser Pro Asp Ser Phe Arg Arg Leu Asn His Leu Glu Glu Ile Asp Leu
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Arg Cys Asn Cys Val Pro Val Leu Leu Gly Ser Lys Ala Asn Val Cys
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Thr Lys Arg Leu Gln Ile Arg Pro Gly Ser Phe Ser Gly Leu Ser Asp
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Leu Lys Ala Leu Tyr Leu Asp Gly Asn Gln Leu Leu Glu Ile Pro Gln
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Asp Leu Pro Ser Ser Leu His Leu Leu Ser Leu Glu Ala Asn Asn Ile
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Phe Ser Ile Thr Lys Glu Asn Leu Thr Glu Leu Val Asn Ile Glu Thr
165 170 175

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Tyr Ser Ile Glu Lys Asp Ala Phe Leu Val Met Arg Asn Leu Lys Val
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Pro Asn Leu Leu Glu Leu Tyr Leu Tyr Asn Asn Ile Ile Lys Lys Ile
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Gln Glu Asn Asp Phe Asn Asn Leu Asn Glu Leu Gln Val Leu Asp Leu
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Cys Glu Asn Asn Ser Pro Leu Gln Ile His Asp Asn Ala Phe Asn Ser
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Val Pro Pro Thr Trp Phe Lys Asn Met Arg Asn Leu Gln Glu Leu Asp
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325 330 335

His Phe Leu Pro Asn Leu Val Glu Leu Asp Phe Ser Phe Asn Tyr Glu
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Leu Gln Val Tyr His Ala Ser Ile Thr Leu Pro His Ser Leu Ser Ser
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Leu Lys Asn Ser Ser Leu Ser Val Leu His Lys Leu Pro Arg Leu Glu
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Val Leu Asp Leu Gly Thr Asn Phe Ile Lys Ile Ala Asp Leu Asn Ile
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Phe Lys His Phe Glu Asn Leu Lys Leu Ile Asp Leu Ser Val Asn Lys
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Gln Thr Leu Asp Leu Ser Arg Asn Asn Ile Phe Phe Ile Lys Pro Ser
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Thr Lys Lys Leu Arg Leu Leu Asp Lys Leu Met Met Asn Asp Asn Asp
595 600 605

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Asp Ile Ser Arg Asn Ser Leu Asn Ser Leu Pro Pro Glu Val Phe Glu
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Gly Met Pro Pro Asn Leu Lys Asn Leu Ser Leu Ala Lys Asn Gly Leu
675 680 685

Lys Ser Phe Phe Trp Asp Arg Leu Gln Leu Leu Lys His Leu Glu Ile
690 695 700

Leu Asp Leu Ser His Asn Gln Leu Thr Lys Val Pro Glu Arg Leu Ala
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Asn Cys Ser Lys Ser Leu Thr Thr Leu Ile Leu Lys His Asn Gln Ile
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Arg Gln Leu Thr Lys Tyr Phe Leu Glu Asp Ala Leu Gln Leu Arg Tyr
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Leu Asp Ile Ser Ser Asn Lys Ile Gln Val Ile Gln Lys Thr Ser Phe
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770 775 780

Arg Phe Leu Cys Asn Cys Asp Ala Val Trp Phe Val Trp Trp Val Asn
785 790 795 800

His Thr Asp Val Thr Ile Pro Tyr Leu Ala Thr Asp Val Thr Cys Val
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Gly Pro Gly Ala His Lys Gly Gln Ser Val Ile Ser Leu Asp Leu Tyr
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Thr Cys Glu Leu Asp Leu Thr Asn Leu Ile Leu Phe Ser Val Ser Ile
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Ser Ser Val Leu Phe Leu Met Val Val Met Thr Thr Ser His Leu Phe
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Phe Trp Asp Met Trp Tyr Ile Tyr Tyr Phe Trp Lys Ala Lys Ile Lys
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Gly Tyr Gln His Leu Gln Ser Met Glu Ser Cys Tyr Asp Ala Phe Ile
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Val Tyr Asp Thr Lys Asn Ser Ala Val Thr Glu Trp Val Leu Gln Glu
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Glu Lys Pro Leu Gln Lys Ser Lys Phe Leu Gln Leu Arg Lys Arg Leu
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Val Thr Glu Leu Asp Leu Ser Asp Asn Phe Ile Thr His Ile Thr Asn
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Glu Ser Phe Gln Gly Leu Gln Asn Leu Thr Lys Ile Asn Leu Asn His
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Glu Leu Leu Leu Glu Asp Asn Gln Leu Pro Gln Ile Pro Ser Gly Leu
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Ile Thr Lys Glu Gly Ile Ser Arg Leu Ile Asn Leu Lys Asn Leu Tyr
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Leu Ala Trp Asn Cys Tyr Phe Asn Lys Val Cys Glu Lys Thr Asn Ile
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Glu Asp Gly Val Phe Glu Thr Leu Thr Asn Leu Glu Leu Leu Ser Leu
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Ser Phe Asn Ser Leu Ser His Val Pro Pro Lys Leu Pro Ser Ser Leu
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Cys Pro Arg Cys Phe Asn Ala Pro Phe Pro Cys Val Pro Cys Asp Gly
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Pro Arg Leu Glu Ile Leu Asp Leu Ser Phe Asn Tyr Ile Lys Gly Ser
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Tyr Pro Gln His Ile Asn Ile Ser Arg Asn Phe Ser Lys Leu Leu Ser
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Leu Arg Ala Leu His Leu Arg Gly Tyr Val Phe Gln Glu Leu Arg Glu
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Asp Asp Phe Gln Pro Leu Met Gln Leu Pro Asn Leu Ser Thr Ile Asn
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Leu Gly Ile Asn Phe Ile Lys Gln Ile Asp Phe Lys Leu Phe Gln Asn
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Phe Ser Asn Leu Glu Ile Ile Tyr Leu Ser Glu Asn Arg Ile Ser Pro
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Leu Val Lys Asp Thr Arg Gln Ser Tyr Ala Asn Ser Ser Ser Phe Gln
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Leu Glu Phe Ile Gln Asn Phe Thr Asn Leu Lys Val Leu Asn Leu Ser
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Ser Leu Val Glu Leu Val Phe Ser Gly Asn Arg Leu Asp Ile Leu Trp
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675 680 685

Arg Leu Glu Leu Leu Asp Leu Arg Gly Asn Lys Leu Leu Phe Leu Thr
690 695 700

Asp Ser Leu Ser Asp Phe Thr Ser Ser Leu Arg Thr Leu Leu Leu Ser
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725 730 735

Ser Leu Lys His Leu Asp Leu Ser Ser Asn Leu Leu Lys Thr Ile Asn
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Lys Ser Ala Leu Glu Thr Lys Thr Thr Thr Lys Leu Ser Met Leu Glu
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Leu His Gly Asn Pro Phe Glu Cys Thr Cys Asp Ile Gly Asp Phe Arg
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Arg Trp Met Asp Glu His Leu Asn Val Lys Ile Pro Arg Leu Val Asp
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Val Ile Cys Ala Ser Pro Gly Asp Gln Arg Gly Lys Ser Ile Val Ser
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Leu Glu Leu Thr Thr Cys Val Ser Asp Val Thr Ala Val Ile Leu Phe
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Phe Phe Thr Phe Phe Ile Thr Thr Met Val Met Leu Ala Ala Leu Ala
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Ala Lys Val Lys Gly Tyr Arg Ser Leu Ser Thr Ser Gln Thr Phe Tyr
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Asp Ala Tyr Ile Ser Tyr Asp Thr Lys Asp Ala Ser Val Thr Asp Trp
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Val Ile Asn Glu Leu Arg Tyr His Leu Glu Glu Ser Arg Asp Lys Asn
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Val Leu Thr Lys Lys Tyr Ala Lys Ser Trp Asn Phe Lys Thr Ala Phe
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Tyr Leu Ala Leu Gln Arg Leu Met Asp Glu Asn Met Asp Val Ile Ile
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Phe Ile Leu Leu Glu Pro Val Leu Gln His Ser Gln Tyr Leu Arg Leu
980 985 990

Arg Gln Arg Ile Cys Lys Ser Ser Ile Leu Gln Trp Pro Asp Asn Pro
995 1000 1005

Lys Ala Glu Gly Leu Phe Trp Gln Thr Leu Arg Asn Val Val Leu
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Phe Leu Leu Ile Ser Gly Ser Cys Glu Leu Cys Ala Glu Glu Asn Phe
35 40 45

Ser Arg Ser Tyr Pro Cys Asp Glu Lys Lys Gln Asn Asp Ser Val Ile
50 55 60

Ala Glu Cys Ser Asn Arg Arg Leu Gln Glu Val Pro Gln Thr Val Gly
65 70 75 80

Lys Tyr Val Thr Glu Leu Asp Leu Ser Asp Asn Phe Ile Thr His Ile
85 90 95

Thr Asn Glu Ser Phe Gln Gly Leu Gln Asn Leu Thr Lys Ile Asn Leu
100 105 110

Asn His Asn Pro Asn Val Gln His Gln Asn Gly Asn Pro Gly Ile Gln
115 120 125

Ser Asn Gly Leu Asn Ile Thr Asp Gly Ala Phe Leu Asn Leu Lys Asn
130 135 140

Leu Arg Glu Leu Leu Leu Glu Asp Asn Gln Leu Pro Gln Ile Pro Ser
145 150 155 160

Gly Leu Pro Glu Ser Leu Thr Glu Leu Ser Leu Ile Gln Asn Asn Ile
165 170 175

Tyr Asn Ile Thr Lys Glu Gly Ile Ser Arg Leu Ile Asn Leu Lys Asn
180 185 190

Leu Tyr Leu Ala Trp Asn Cys Tyr Phe Asn Lys Val Cys Glu Lys Thr
195 200 205

Asn Ile Glu Asp Gly Val Phe Glu Thr Leu Thr Asn Leu Glu Leu Leu
210 215 220

Ser Leu Ser Phe Asn Ser Leu Ser His Val Ser Pro Lys Leu Pro Ser
225 230 235 240

Ser Leu Arg Lys Leu Phe Leu Ser Asn Thr Gln Ile Lys Tyr Ile Ser
245 250 255

Glu Glu Asp Phe Lys Gly Leu Ile Asn Leu Thr Leu Leu Asp Leu Ser
260 265 270

Gly Asn Cys Pro Arg Cys Phe Asn Ala Pro Phe Pro Cys Val Pro Cys
275 280 285

Asp Gly Gly Ala Ser Ile Asn Ile Asp Arg Phe Ala Phe Gln Asn Leu
290 295 300

Thr Gln Leu Arg Tyr Leu Asn Leu Ser Ser Thr Ser Leu Arg Lys Ile
305 310 315 320

Asn Ala Ala Trp Phe Lys Asn Met Pro His Leu Lys Val Leu Asp Leu
325 330 335

Glu Phe Asn Tyr Leu Val Gly Glu Ile Ala Ser Gly Ala Phe Leu Thr
340 345 350

Met Leu Pro Arg Leu Glu Ile Leu Asp Leu Ser Phe Asn Tyr Ile Lys
355 360 365

Gly Ser Tyr Pro Gln His Ile Asn Ile Ser Arg Asn Phe Ser Lys Pro
370 375 380

Leu Ser Leu Arg Ala Leu His Leu Arg Gly Tyr Val Phe Gln Glu Leu
385 390 395 400

Arg Glu Asp Asp Phe Gln Pro Leu Met Gln Leu Pro Asn Leu Ser Thr
405 410 415

Ile Asn Leu Gly Ile Asn Phe Ile Lys Gln Ile Asp Phe Lys Leu Phe
420 425 430

Gln Asn Phe Ser Asn Leu Glu Ile Ile Tyr Leu Ser Glu Asn Arg Ile
435 440 445

Ser Pro Leu Val Lys Asp Thr Arg Gln Ser Tyr Ala Asn Ser Ser Ser
450 455 460

Phe Gln Arg His Ile Arg Lys Arg Arg Ser Thr Asp Phe Glu Phe Asp
465 470 475 480

Pro His Ser Asn Phe Tyr His Phe Thr Arg Pro Leu Ile Lys Pro Gln
485 490 495

Cys Ala Ala Tyr Gly Lys Ala Leu Asp Leu Ser Leu Asn Ser Ile Phe
500 505 510

Phe Ile Gly Pro Asn Gln Phe Glu Asn Leu Pro Asp Ile Ala Cys Leu
515 520 525

Asn Leu Ser Ala Asn Ser Asn Ala Gln Val Leu Ser Gly Thr Glu Phe
530 535 540

Ser Ala Ile Pro His Val Lys Tyr Leu Asp Leu Thr Asn Asn Arg Leu
545 550 555 560

Asp Phe Asp Asn Ala Ser Ala Leu Thr Glu Leu Ser Asp Leu Glu Val
565 570 575

Leu Asp Leu Ser Tyr Asn Ser His Tyr Phe Arg Ile Ala Gly Val Thr
580 585 590

His His Leu Glu Phe Ile Gln Asn Phe Thr Asn Leu Lys Val Leu Asn
595 600 605

Leu Ser His Asn Asn Ile Tyr Thr Leu Thr Asp Lys Tyr Asn Leu Glu
610 615 620

Ser Lys Ser Leu Val Glu Leu Val Phe Ser Gly Asn Arg Leu Asp Ile
625 630 635 640

Leu Trp Asn Asp Asp Asp Asn Arg Tyr Ile Ser Ile Phe Lys Gly Leu
645 650 655

Lys Asn Leu Thr Arg Leu Asp Leu Ser Leu Asn Arg Leu Lys His Ile
660 665 670

Pro Asn Glu Ala Phe Leu Asn Leu Pro Ala Ser Leu Thr Glu Leu His
675 680 685

Ile Asn Asp Asn Met Leu Lys Phe Phe Asn Trp Thr Leu Leu Gln Gln
690 695 700

Phe Pro Arg Leu Glu Leu Leu Asp Leu Arg Gly Asn Lys Leu Leu Phe
705 710 715 720

Leu Thr Asp Ser Leu Ser Asp Phe Thr Ser Ser Leu Arg Thr Leu Leu
725 730 735

Leu Ser His Asn Arg Ile Ser His Leu Pro Ser Gly Phe Leu Ser Glu
740 745 750

Val Ser Ser Leu Lys His Leu Asp Leu Ser Ser Asn Leu Leu Lys Thr
755 760 765

Ile Asn Lys Ser Ala Leu Glu Thr Lys Thr Thr Thr Lys Leu Ser Met
770 775 780

Leu Glu Leu His Gly Asn Pro Phe Glu Cys Thr Cys Asp Ile Gly Asp
785 790 795 800

Phe Arg Arg Trp Met Asp Glu His Leu Asn Val Lys Ile Pro Arg Leu
805 810 815

Val Asp Val Ile Cys Ala Ser Pro Gly Asp Gln Arg Gly Lys Ser Ile
820 825 830

Val Ser Leu Glu Leu Thr Thr Cys Val Ser Asp Val Thr Ala Val Ile
835 840 845

Leu Phe Phe Phe Thr Phe Phe Ile Thr Thr Met Val Met Leu Ala Ala
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Leu Ala His His Leu Phe Tyr Trp Asp Val Trp Phe Ile Tyr Asn Val
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Cys Leu Ala Lys Ile Lys Gly Tyr Arg Ser Leu Ser Thr Ser Gln Thr
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Phe Tyr Asp Ala Tyr Ile Ser Tyr Asp Thr Lys Asp Ala Ser Val Thr
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Asp Trp Val Ile Asn Glu Leu Arg Tyr His Leu Glu Glu Ser Arg Asp
        915   920   925

Lys Asn Val Leu Leu Cys Leu Glu Glu Arg Asp Trp Asp Pro Gly Leu
    930   935   940

Ala Ile Ile Asp Asn Leu Met Gln Ser Ile Asn Gln Ser Lys Lys Thr
945   950   955   960

Val Phe Val Leu Thr Lys Lys Tyr Ala Lys Ser Trp Asn Phe Lys Thr
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Ala Phe Tyr Leu Ala Leu Gln Arg Leu Met Asp Glu Asn Met Asp Val
            980   985   990

Ile Ile Phe Ile Leu Leu Glu Pro Val Leu Gln His Ser Gln Tyr Leu
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Arg Leu Arg Gln Arg Ile Cys Lys Ser Ser Ile Leu Gln Trp Pro
    1010   1015   1020

Asp Asn Pro Lys Ala Glu Gly Leu Phe Trp Gln Thr Leu Arg Asn
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Asp Ser Ile Lys Gln Tyr
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tggcttgaat atcacagacg gggcattcct caacctaaaa aacctaaggg agttactgct 600

tgaagacaac cagttacccc aaataccctc tggtttgcca gagtctttga cagaacttag 660

tctaattcaa aacaatatat acaacataac taaagagggc atttcaagac ttataaactt 720

gaaaaatctc tatttggcct ggaactgcta ttttaacaaa gtttgcgaga aaactaacat 780

agaagatgga gtatttgaaa cgctgacaaa tttggagttg ctatcactat ctttcaattc 840

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ataaaga 3367

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<213> Mus musculus

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Ser Tyr Pro Cys Asp Glu Ile Arg His Asn Ser Leu Val Ile Ala Glu
35 40 45

Cys Asn His Arg Gln Leu His Glu Val Pro Gln Thr Ile Gly Lys Tyr
50 55 60

Val Thr Asn Ile Asp Leu Ser Asp Asn Ala Ile Thr His Ile Thr Lys
65 70 75 80

Glu Ser Phe Gln Lys Leu Gln Asn Leu Thr Lys Ile Asp Leu Asn His
85 90 95

Asn Ala Lys Gln Gln His Pro Asn Glu Asn Lys Asn Gly Met Asn Ile
100 105 110

Thr Glu Gly Ala Leu Leu Ser Leu Arg Asn Leu Thr Val Leu Leu Leu
115 120 125

Glu Asp Asn Gln Leu Tyr Thr Ile Pro Ala Gly Leu Pro Glu Ser Leu
130 135 140

Lys Glu Leu Ser Leu Ile Gln Asn Asn Ile Phe Gln Val Thr Lys Asn
145 150 155 160

Asn Thr Phe Gly Leu Arg Asn Leu Glu Arg Leu Tyr Leu Gly Trp Asn
165 170 175

Cys Tyr Phe Lys Cys Asn Gln Thr Phe Lys Val Glu Asp Gly Ala Phe
180 185 190

Lys Asn Leu Ile His Leu Lys Val Leu Ser Leu Ser Phe Asn Asn Leu
195 200 205

Phe Tyr Val Pro Pro Lys Leu Pro Ser Ser Leu Arg Lys Leu Phe Leu
210 215 220

Ser Asn Ala Lys Ile Met Asn Ile Thr Gln Glu Asp Phe Lys Gly Leu
225 230 235 240

Glu Asn Leu Thr Leu Leu Asp Leu Ser Gly Asn Cys Pro Arg Cys Tyr
245 250 255

Asn Ala Pro Phe Pro Cys Thr Pro Cys Lys Glu Asn Ser Ser Ile His
260 265 270

275 280 285

Leu Ser Ser Thr Ser Leu Arg Thr Ile Pro Ser Thr Trp Phe Glu Asn
290 295 300

Leu Ser Asn Leu Lys Glu Leu His Leu Glu Phe Asn Tyr Leu Val Gln
305 310 315 320

Glu Ile Ala Ser Gly Ala Phe Leu Thr Lys Leu Pro Ser Leu Gln Ile
325 330 335

Leu Asp Leu Ser Phe Asn Phe Gln Tyr Lys Glu Tyr Leu Gln Phe Ile
340 345 350

Asn Ile Ser Ser Asn Phe Ser Lys Leu Arg Ser Leu Lys Lys Leu His
355 360 365

Leu Arg Gly Tyr Val Phe Arg Glu Leu Lys Lys Lys His Phe Glu His
370 375 380

Leu Gln Ser Leu Pro Asn Leu Ala Thr Ile Asn Leu Gly Ile Asn Phe
385 390 395 400

Ile Glu Lys Ile Asp Phe Lys Ala Phe Gln Asn Phe Ser Lys Leu Asp
405 410 415

Val Ile Tyr Leu Ser Gly Asn Arg Ile Ala Ser Val Leu Asp Gly Thr
420 425 430

Asp Tyr Ser Ser Trp Arg Asn Arg Leu Arg Lys Pro Leu Ser Thr Asp
435 440 445

Asp Asp Glu Phe Asp Pro His Val Asn Phe Tyr His Ser Thr Lys Pro
450 455 460

Leu Ile Lys Pro Gln Cys Thr Ala Tyr Gly Lys Ala Leu Asp Leu Ser
465 470 475 480

Leu Asn Asn Ile Phe Ile Ile Gly Lys Ser Gln Phe Glu Gly Phe Gln
485 490 495

Asp Ile Ala Cys Leu Asn Leu Ser Phe Asn Ala Asn Thr Gln Val Phe
500 505 510

Asn Gly Thr Glu Phe Ser Ser Met Pro His Ile Lys Tyr Leu Asp Leu
515 520 525

Thr Asn Asn Arg Leu Asp Phe Asp Asp Asn Asn Ala Phe Ser Asp Leu
530 535 540

His Asp Leu Glu Val Leu Asp Leu Ser His Asn Ala His Tyr Phe Ser
545 550 555 560

Ile Ala Gly Val Thr His Arg Leu Gly Phe Ile Gln Asn Leu Ile Asn
565 570 575

Leu Arg Val Leu Asn Leu Ser His Asn Gly Ile Tyr Thr Leu Thr Glu
580 585 590

Glu Ser Glu Leu Lys Ser Ile Ser Leu Lys Glu Leu Val Phe Ser Gly
595 600 605

Asn Arg Leu Asp His Leu Trp Asn Ala Asn Asp Gly Lys Tyr Trp Ser
610 615 620

Ile Phe Lys Ser Leu Gln Asn Leu Ile Arg Leu Asp Leu Ser Tyr Asn
625 630 635 640

Asn Leu Gln Gln Ile Pro Asn Gly Ala Phe Leu Asn Leu Pro Gln Ser
645 650 655

Leu Gln Glu Leu Leu Ile Ser Gly Asn Lys Leu Arg Phe Phe Asn Trp
660 665 670

Thr Leu Leu Gln Tyr Phe Pro His Leu His Leu Leu Asp Leu Ser Arg
675 680 685

Asn Glu Leu Tyr Phe Leu Pro Asn Cys Leu Ser Lys Phe Ala His Ser
690 695 700

Leu Glu Thr Leu Leu Leu Ser His Asn His Phe Ser His Leu Pro Ser
705 710 715 720

Gly Phe Leu Ser Glu Ala Arg Asn Leu Val His Leu Asp Leu Ser Phe
725 730 735

Asn Thr Ile Lys Met Ile Asn Lys Ser Ser Leu Gln Thr Lys Met Lys
740 745 750

Thr Asn Leu Ser Ile Leu Glu Leu His Gly Asn Tyr Phe Asp Cys Thr
755 760 765

Cys Asp Ile Ser Asp Phe Arg Ser Trp Leu Asp Glu Asn Leu Asn Ile
770 775 780

785 790 795 800

Lys Ser Lys Ser Ile Met Ser Leu Asp Leu Thr Thr Cys Val Ser Asp
805 810 815

Thr Thr Ala Ala Val Leu Phe Phe Leu Thr Phe Leu Thr Thr Ser Met
820 825 830

Val Met Leu Ala Ala Leu Val His His Leu Phe Tyr Trp Asp Val Trp
835 840 845

Phe Ile Tyr His Met Cys Ser Ala Lys Leu Lys Gly Tyr Arg Thr Ser
850 855 860

Ser Thr Ser Gln Thr Phe Tyr Asp Ala Tyr Ile Ser Tyr Asp Thr Lys
865 870 875 880

Asp Ala Ser Val Thr Asp Trp Val Ile Asn Glu Leu Arg Tyr His Leu
885 890 895

Glu Glu Ser Glu Asp Lys Ser Val Leu Leu Cys Leu Glu Glu Arg Asp
900 905 910

Trp Asp Pro Gly Leu Pro Ile Ile Asp Asn Leu Met Gln Ser Ile Asn
915 920 925

Gln Ser Lys Lys Thr Ile Phe Val Leu Thr Lys Lys Tyr Ala Lys Ser
930 935 940

Trp Asn Phe Lys Thr Ala Phe Tyr Leu Ala Leu Gln Arg Leu Met Asp
945 950 955 960

Glu Asn Met Asp Val Ile Ile Phe Ile Leu Leu Glu Pro Val Leu Gln
965 970 975

Tyr Ser Gln Tyr Leu Arg Leu Arg Gln Arg Ile Cys Lys Ser Ser Ile
980 985 990

Leu Gln Trp Pro Asn Asn Pro Lys Ala Glu Asn Leu Phe Trp Gln Ser
995 1000 1005

Leu Lys Asn Val Val Leu Thr Glu Asn Asp Ser Arg Tyr Asp Asp
1010 1015 1020

Leu Tyr Ile Asp Ser Ile Arg Gln Tyr
1025 1030

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caactccctt gtgattgcag aatgcaacca tcgtcaactg catgaagttc cccaaactat 240

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gcacccaaat gaaaataaaa atggtatgaa tattacagaa ggggcacttc tcagcctaag 420

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atactggtcc atttttaaaa gtctccagaa tttgatacgc ctggacttat catacaataa 1980

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<212>  PRT
<213>  Homo sapiens

<400>  34

Met Gly Phe Cys Arg Ser Ala Leu His Pro Leu Ser Leu Leu Val Gln
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Ala Ile Met Leu Ala Met Thr Leu Ala Leu Gly Thr Leu Pro Ala Phe
            20                  25                  30

Leu Pro Cys Glu Leu Gln Pro His Gly Leu Val Asn Cys Asn Trp Leu
        35                  40                  45

Phe Leu Lys Ser Val Pro His Phe Ser Met Ala Ala Pro Arg Gly Asn
    50                  55                  60

Val Thr Ser Leu Ser Leu Ser Ser Asn Arg Ile His His Leu His Asp
65                  70                  75                  80

Ser Asp Phe Ala His Leu Pro Ser Leu Arg His Leu Asn Leu Lys Trp
                85                  90                  95

Asn Cys Pro Pro Val Gly Leu Ser Pro Met His Phe Pro Cys His Met
            100                 105                 110
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Thr Ile Glu Pro Ser Thr Phe Leu Ala Val Pro Thr Leu Glu Glu Leu
115 120 125

Asn Leu Ser Tyr Asn Asn Ile Met Thr Val Pro Ala Leu Pro Lys Ser
130 135 140

Leu Ile Ser Leu Ser Leu Ser His Thr Asn Ile Leu Met Leu Asp Ser
145 150 155 160

Ala Ser Leu Ala Gly Leu His Ala Leu Arg Phe Leu Phe Met Asp Gly
165 170 175

Asn Cys Tyr Tyr Lys Asn Pro Cys Arg Gln Ala Leu Glu Val Ala Pro

Gly Ala Leu Leu Gly Leu Gly Asn Leu Thr His Leu Ser Leu Lys Tyr
195 200 205

Asn Asn Leu Thr Val Val Pro Arg Asn Leu Pro Ser Ser Leu Glu Tyr
210 215 220

Leu Leu Leu Ser Tyr Asn Arg Ile Val Lys Leu Ala Pro Glu Asp Leu
225 230 235 240

Ala Asn Leu Thr Ala Leu Arg Val Leu Asp Val Gly Gly Asn Cys Arg
245 250 255

Arg Cys Asp His Ala Pro Asn Pro Cys Met Glu Cys Pro Arg His Phe
260 265 270

Pro Gln Leu His Pro Asp Thr Phe Ser His Leu Ser Arg Leu Glu Gly
275 280 285

Leu Val Leu Lys Asp Ser Ser Leu Ser Trp Leu Asn Ala Ser Trp Phe
290 295 300

Arg Gly Leu Gly Asn Leu Arg Val Leu Asp Leu Ser Glu Asn Phe Leu
305 310 315 320

Tyr Lys Cys Ile Thr Lys Thr Lys Ala Phe Gln Gly Leu Thr Gln Leu
325 330 335

Arg Lys Leu Asn Leu Ser Phe Asn Tyr Gln Lys Arg Val Ser Phe Ala
340 345 350

```
His Leu Ser Leu Ala Pro Ser Phe Gly Ser Leu Val Ala Leu Lys Glu
        355                 360                 365

Leu Asp Met His Gly Ile Phe Phe Arg Ser Leu Asp Glu Thr Thr Leu
    370                 375                 380

Arg Pro Leu Ala Arg Leu Pro Met Leu Gln Thr Leu Arg Leu Gln Met
385                 390                 395                 400

Asn Phe Ile Asn Gln Ala Gln Leu Gly Ile Phe Arg Ala Phe Pro Gly
                405                 410                 415

Leu Arg Tyr Val Asp Leu Ser Asp Asn Arg Ile Ser Gly Ala Ser Glu
            420                 425                 430

Leu Thr Ala Thr Met Gly Glu Ala Asp Gly Gly Glu Lys Val Trp Leu
        435                 440                 445

Gln Pro Gly Asp Leu Ala Pro Ala Pro Val Asp Thr Pro Ser Ser Glu
    450                 455                 460

Asp Phe Arg Pro Asn Cys Ser Thr Leu Asn Phe Thr Leu Asp Leu Ser
465                 470                 475                 480

Arg Asn Asn Leu Val Thr Val Gln Pro Glu Met Phe Ala Gln Leu Ser
                485                 490                 495

His Leu Gln Cys Leu Arg Leu Ser His Asn Cys Ile Ser Gln Ala Val
            500                 505                 510

Asn Gly Ser Gln Phe Leu Pro Leu Thr Gly Leu Gln Val Leu Asp Leu
        515                 520                 525

Ser His Asn Lys Leu Asp Leu Tyr His Glu His Ser Phe Thr Glu Leu
    530                 535                 540

Pro Arg Leu Glu Ala Leu Asp Leu Ser Tyr Asn Ser Gln Pro Phe Gly
545                 550                 555                 560

Met Gln Gly Val Gly His Asn Phe Ser Phe Val Ala His Leu Arg Thr
                565                 570                 575

Leu Arg His Leu Ser Leu Ala His Asn Asn Ile His Ser Gln Val Ser
            580                 585                 590
```

```
Gln Gln Leu Cys Ser Thr Ser Leu Arg Ala Leu Asp Phe Ser Gly Asn
        595                 600                 605

Ala Leu Gly His Met Trp Ala Glu Gly Asp Leu Tyr Leu His Phe Phe
    610                 615                 620

Gln Gly Leu Ser Gly Leu Ile Trp Leu Asp Leu Ser Gln Asn Arg Leu
625                 630                 635                 640

His Thr Leu Leu Pro Gln Thr Leu Arg Asn Leu Pro Lys Ser Leu Gln
                645                 650                 655

Val Leu Arg Leu Arg Asp Asn Tyr Leu Ala Phe Phe Lys Trp Trp Ser
            660                 665                 670

Leu His Phe Leu Pro Lys Leu Glu Val Leu Asp Leu Ala Gly Asn Gln
        675                 680                 685

Leu Lys Ala Leu Thr Asn Gly Ser Leu Pro Ala Gly Thr Arg Leu Arg

Arg Leu Asp Val Ser Cys Asn Ser Ile Ser Phe Val Ala Pro Gly Phe
705                 710                 715                 720

Phe Ser Lys Ala Lys Glu Leu Arg Glu Leu Asn Leu Ser Ala Asn Ala
                725                 730                 735

Leu Lys Thr Val Asp His Ser Trp Phe Gly Pro Leu Ala Ser Ala Leu
            740                 745                 750

Gln Ile Leu Asp Val Ser Ala Asn Pro Leu His Cys Ala Cys Gly Ala
        755                 760                 765

Ala Phe Met Asp Phe Leu Leu Glu Val Gln Ala Ala Val Pro Gly Leu
    770                 775                 780

Pro Ser Arg Val Lys Cys Gly Ser Pro Gly Gln Leu Gln Gly Leu Ser
785                 790                 795                 800

Ile Phe Ala Gln Asp Leu Arg Leu Cys Leu Asp Glu Ala Leu Ser Trp
                805                 810                 815

Asp Cys Phe Ala Leu Ser Leu Leu Ala Val Ala Leu Gly Leu Gly Val
            820                 825                 830
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Pro Met Leu His His Leu Cys Gly Trp Asp Leu Trp Tyr Cys Phe His
        835                 840                 845

Leu Cys Leu Ala Trp Leu Pro Trp Arg Gly Arg Gln Ser Gly Arg Asp
    850                 855                 860

Glu Asp Ala Leu Pro Tyr Asp Ala Phe Val Val Phe Asp Lys Thr Gln
865                 870                 875                 880

Ser Ala Val Ala Asp Trp Val Tyr Asn Glu Leu Arg Gly Gln Leu Glu
                885                 890                 895

Glu Cys Arg Gly Arg Trp Ala Leu Arg Leu Cys Leu Glu Glu Arg Asp
            900                 905                 910

Trp Leu Pro Gly Lys Thr Leu Phe Glu Asn Leu Trp Ala Ser Val Tyr
        915                 920                 925

Gly Ser Arg Lys Thr Leu Phe Val Leu Ala His Thr Asp Arg Val Ser
    930                 935                 940

Gly Leu Leu Arg Ala Ser Phe Leu Leu Ala Gln Gln Arg Leu Leu Glu
945                 950                 955                 960

Asp Arg Lys Asp Val Val Val Leu Val Ile Leu Ser Pro Asp Gly Arg
                965                 970                 975

Arg Ser Arg Tyr Val Arg Leu Arg Gln Arg Leu Cys Arg Gln Ser Val
            980                 985                 990

Leu Leu Trp Pro His Gln Pro Ser  Gly Gln Arg Ser Phe  Trp Ala Gln
        995                 1000                 1005

Leu Gly  Met Ala Leu Thr Arg  Asp Asn His His Phe  Tyr Asn Arg
    1010                 1015                 1020

Asn Phe  Cys Gln Gly Pro Thr  Ala Glu
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<210> 35
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<213> Homo sapiens

<400> 35

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<211> 1055
<212> PRT
<213> Homo sapiens

<400> 36

Met Pro Met Lys Trp Ser Gly Trp Arg Trp Ser Trp Gly Pro Ala Thr
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His Thr Ala Leu Pro Pro Pro Gln Gly Phe Cys Arg Ser Ala Leu His
20 25 30

Pro Leu Ser Leu Leu Val Gln Ala Ile Met Leu Ala Met Thr Leu Ala
35 40 45

Leu Gly Thr Leu Pro Ala Phe Leu Pro Cys Glu Leu Gln Pro His Gly
50 55 60

Leu Val Asn Cys Asn Trp Leu Phe Leu Lys Ser Val Pro His Phe Ser
65 70 75 80

Met Ala Ala Pro Arg Gly Asn Val Thr Ser Leu Ser Leu Ser Ser Asn
85 90 95

Arg Ile His His Leu His Asp Ser Asp Phe Ala His Leu Pro Ser Leu
100 105 110

Arg His Leu Asn Leu Lys Trp Asn Cys Pro Pro Val Gly Leu Ser Pro
115 120 125

Met His Phe Pro Cys His Met Thr Ile Glu Pro Ser Thr Phe Leu Ala
130 135 140

Val Pro Thr Leu Glu Glu Leu Asn Leu Ser Tyr Asn Asn Ile Met Thr
145 150 155 160

Val Pro Ala Leu Pro Lys Ser Leu Ile Ser Leu Ser Leu Ser His Thr
165 170 175

Asn Ile Leu Met Leu Asp Ser Ala Ser Leu Ala Gly Leu His Ala Leu
180 185 190

Arg Phe Leu Phe Met Asp Gly Asn Cys Tyr Tyr Lys Asn Pro Cys Arg
195 200 205

Gln Ala Leu Glu Val Ala Pro Gly Ala Leu Leu Gly Leu Gly Asn Leu
210 215 220

Thr His Leu Ser Leu Lys Tyr Asn Asn Leu Thr Val Val Pro Arg Asn
225 230 235 240

Leu Pro Ser Ser Leu Glu Tyr Leu Leu Leu Ser Tyr Asn Arg Ile Val
245 250 255

Lys Leu Ala Pro Glu Asp Leu Ala Asn Leu Thr Ala Leu Arg Val Leu
260 265 270

Asp Val Gly Gly Asn Cys Arg Arg Cys Asp His Ala Pro Asn Pro Cys
275 280 285

Met Glu Cys Pro Arg His Phe Pro Gln Leu His Pro Asp Thr Phe Ser
290 295 300

His Leu Ser Arg Leu Glu Gly Leu Val Leu Lys Asp Ser Ser Leu Ser
305 310 315 320

Trp Leu Asn Ala Ser Trp Phe Arg Gly Leu Gly Asn Leu Arg Val Leu
325 330 335

Asp Leu Ser Glu Asn Phe Leu Tyr Lys Cys Ile Thr Lys Thr Lys Ala
340 345 350

Phe Gln Gly Leu Thr Gln Leu Arg Lys Leu Asn Leu Ser Phe Asn Tyr
355 360 365

Gln Lys Arg Val Ser Phe Ala His Leu Ser Leu Ala Pro Ser Phe Gly
370 375 380

Ser Leu Val Ala Leu Lys Glu Leu Asp Met His Gly Ile Phe Phe Arg
385 390 395 400

Ser Leu Asp Glu Thr Thr Leu Arg Pro Leu Ala Arg Leu Pro Met Leu
405 410 415

Gln Thr Leu Arg Leu Gln Met Asn Phe Ile Asn Gln Ala Gln Leu Gly
420 425 430

Ile Phe Arg Ala Phe Pro Gly Leu Arg Tyr Val Asp Leu Ser Asp Asn
435 440 445

450 455 460

Gly Gly Glu Lys Val Trp Leu Gln Pro Gly Asp Leu Ala Pro Ala Pro
465 470 475 480

Val Asp Thr Pro Ser Ser Glu Asp Phe Arg Pro Asn Cys Ser Thr Leu
485 490 495

Asn Phe Thr Leu Asp Leu Ser Arg Asn Asn Leu Val Thr Val Gln Pro
500 505 510

Glu Met Phe Ala Gln Leu Ser His Leu Gln Cys Leu Arg Leu Ser His
515 520 525

Asn Cys Ile Ser Gln Ala Val Asn Gly Ser Gln Phe Leu Pro Leu Thr
530 535 540

Gly Leu Gln Val Leu Asp Leu Ser His Asn Lys Leu Asp Leu Tyr His
545 550 555 560

Glu His Ser Phe Thr Glu Leu Pro Arg Leu Glu Ala Leu Asp Leu Ser
565 570 575

Tyr Asn Ser Gln Pro Phe Gly Met Gln Gly Val Gly His Asn Phe Ser
580 585 590

Phe Val Ala His Leu Arg Thr Leu Arg His Leu Ser Leu Ala His Asn
595 600 605

Asn Ile His Ser Gln Val Ser Gln Gln Leu Cys Ser Thr Ser Leu Arg
610 615 620

Ala Leu Asp Phe Ser Gly Asn Ala Leu Gly His Met Trp Ala Glu Gly
625 630 635 640

Asp Leu Tyr Leu His Phe Phe Gln Gly Leu Ser Gly Leu Ile Trp Leu
645 650 655

Asp Leu Ser Gln Asn Arg Leu His Thr Leu Leu Pro Gln Thr Leu Arg
660 665 670

Asn Leu Pro Lys Ser Leu Gln Val Leu Arg Leu Arg Asp Asn Tyr Leu
675 680 685

Ala Phe Phe Lys Trp Trp Ser Leu His Phe Leu Pro Lys Leu Glu Val
690 695 700

Leu Asp Leu Ala Gly Asn Gln Leu Lys Ala Leu Thr Asn Gly Ser Leu
705 710 715 720

Pro Ala Gly Thr Arg Leu Arg Arg Leu Asp Val Ser Cys Asn Ser Ile
725 730 735

Ser Phe Val Ala Pro Gly Phe Phe Ser Lys Ala Lys Glu Leu Arg Glu
740 745 750

Leu Asn Leu Ser Ala Asn Ala Leu Lys Thr Val Asp His Ser Trp Phe
755 760 765

Gly Pro Leu Ala Ser Ala Leu Gln Ile Leu Asp Val Ser Ala Asn Pro
770 775 780

Leu His Cys Ala Cys Gly Ala Ala Phe Met Asp Phe Leu Leu Glu Val
785 790 795 800

Gln Ala Ala Val Pro Gly Leu Pro Ser Arg Val Lys Cys Gly Ser Pro
805 810 815

Gly Gln Leu Gln Gly Leu Ser Ile Phe Ala Gln Asp Leu Arg Leu Cys
820 825 830

Leu Asp Glu Ala Leu Ser Trp Asp Cys Phe Ala Leu Ser Leu Leu Ala
835 840 845

Val Ala Leu Gly Leu Gly Val Pro Met Leu His His Leu Cys Gly Trp
850 855 860

Asp Leu Trp Tyr Cys Phe His Leu Cys Leu Ala Trp Leu Pro Trp Arg
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Gly Arg Gln Ser Gly Arg Asp Glu Asp Ala Leu Pro Tyr Asp Ala Phe
885 890 895

Val Val Phe Asp Lys Thr Gln Ser Ala Val Ala Asp Trp Val Tyr Asn
900 905 910

Glu Leu Arg Gly Gln Leu Glu Glu Cys Arg Gly Arg Trp Ala Leu Arg
915 920 925

Leu Cys Leu Glu Glu Arg Asp Trp Leu Pro Gly Lys Thr Leu Phe Glu
930 935 940

Asn Leu Trp Ala Ser Val Tyr Gly Ser Arg Lys Thr Leu Phe Val Leu

945 950 955 960

965 970 975

Ala Gln Gln Arg Leu Leu Glu Asp Arg Lys Asp Val Val Val Leu Val
980 985 990

Ile Leu Ser Pro Asp Gly Arg Arg Ser Arg Tyr Val Arg Leu Arg Gln
995 1000 1005

Arg Leu Cys Arg Gln Ser Val Leu Leu Trp Pro His Gln Pro Ser
1010 1015 1020

Gly Gln Arg Ser Phe Trp Ala Gln Leu Gly Met Ala Leu Thr Arg
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Asp Asn His His Phe Tyr Asn Arg Asn Phe Cys Gln Gly Pro Thr
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Ile Thr Arg Leu Ser Leu Ile Ser Asn Arg Ile His His Leu His Asn
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Ser Asp Phe Val His Leu Ser Asn Leu Arg Gln Leu Asn Leu Lys Trp
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Asn Cys Pro Pro Thr Gly Leu Ser Pro Leu His Phe Ser Cys His Met
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Leu Val Asn Leu Ser Leu Ser His Thr Asn Ile Leu Val Leu Asp Ala
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Asn Cys Tyr Tyr Lys Asn Pro Cys Thr Gly Ala Val Lys Val Thr Pro
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Gly Ala Leu Leu Gly Leu Ser Asn Leu Thr His Leu Ser Leu Lys Tyr
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Leu Val Leu Lys Asp Ser Ser Leu His Thr Leu Asn Ser Ser Trp Phe
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Gln Gly Leu Val Asn Leu Ser Val Leu Asp Leu Ser Glu Asn Phe Leu
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Tyr Glu Ser Ile Asn His Thr Asn Ala Phe Gln Asn Leu Thr Arg Leu
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Arg Leu His Leu Ala Ser Ser Phe Lys Asn Leu Val Ser Leu Gln Glu
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Arg Trp Leu Ala Asp Leu Pro Lys Leu His Thr Leu His Leu Gln Met
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Leu Arg Phe Val Asp Leu Ser Asp Asn Arg Ile Ser Gly Pro Ser Thr
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Leu Leu Ser Ala Asp Pro His Pro Ala Pro Leu Ser Thr Pro Ala Ser
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Ser Arg Asn Asn Leu Val Thr Ile Lys Pro Glu Met Phe Val Asn Leu
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Val Asn Gly Ser Gln Phe Leu Pro Leu Thr Asn Leu Gln Val Leu Asp
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Ser Met Lys Gly Ile Gly His Asn Phe Ser Phe Val Ala His Leu Ser
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Met Leu His Ser Leu Ser Leu Ala His Asn Asp Ile His Thr Arg Val
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Ser Ser His Leu Asn Ser Asn Ser Val Arg Phe Leu Asp Phe Ser Gly
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Asn Gly Met Gly Arg Met Trp Asp Glu Gly Gly Leu Tyr Leu His Phe
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Gln Leu Lys Ala Leu Thr Asn Gly Thr Leu Pro Asn Gly Thr Leu Leu
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Gln Lys Leu Asp Val Ser Ser Asn Ser Ile Val Ser Val Val Pro Ala
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Leu Thr Val Leu Asp Val Arg Ser Asn Pro Leu His Cys Ala Cys Gly
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Trp Asp Cys Phe Gly Leu Ser Leu Leu Ala Val Ala Val Gly Met Val

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Val Pro Ile Leu His His Leu Cys Gly Trp Asp Val Trp Tyr Cys Phe
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His Leu Cys Leu Ala Trp Leu Pro Leu Leu Ala Arg Ser Arg Arg Ser
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Ala Gln Ala Leu Pro Tyr Asp Ala Phe Val Val Phe Asp Lys Ala Gln
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Asp Arg Lys Asp Val Val Val Leu Val Ile Leu Arg Pro Asp Ala His
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